When describing activities in today’s K–12 science classrooms, the word inquiry often causes some confusion. Inquiry can be an elusive concept, despite the fact that many descriptions and examples are available in the research literature, in national and state science standards, and in science curricula. The models presented in these resources all identify a similar inquiry sequence but vary in the way they define the specific actions students and teachers take in the inquiry process—leaving room for confusion (Nadelson 2009; Llewellyn 2002; Atkin and Karplus 1962; Rutherford and Ahlgren 1990; Milani et al. 1992; AAAS 1993, 1998; NRC 1996, 2000; Anderson 2002; Leonard and Chandler 2003; Leonard 2003; Leonard, Penick, and Speziale 2008) (see “More on inquiry,” p. xx).

Many of us find ourselves asking the same questions: How do we know when inquiry is authentic? What should happen in an inquiry-centered science classroom? What is the teacher’s role in an inquiry-centered class and what is the students’ role? We have thought long and hard about these questions. In this article, we offer suggestions for determining whether your classroom activities are engaging all students in true inquiry.

Is the Inquiry Real?

Working definitions of inquiry in the science classroom
**Inquiry: Teacher and student roles**

Even a cursory review of the literature tells us that the best way for students to learn science concepts effectively, think scientifically, and understand the nature of science is to learn through inquiry (Nadelson 2009; Marshall, Horton, and White 2009). Inquiry learning results in deep understanding of many aspects of science, as opposed to learning through more prescriptive methods. Teachers and students both play an important role in inquiry learning. From our perspective, in authentic inquiry, students typically do the following:

- make initial observations;
- pose (or respond to) researchable questions;
- formulate predictions or cause-and-effect hypotheses to test these research questions;
- plan procedures that identify relevant variables and produce data to test these research questions;
- collect, organize, and display data;
- analyze data and craft tentative inferences to evaluate predictions or hypotheses;
- share ideas, results, and inferences with a group that provides feedback on their potential validity and utility;
- revise, if necessary, the evaluation of the data; and
- reach a formal consensus on answers to the research questions.

If the answers to the original research questions are unclear from the data collected, students prepare new questions, hypotheses, or procedures and conduct additional investigations. Thus the inquiry process starts over again.

The teacher's role is to provide appropriate resources, guide students, and react to student actions. In authentic inquiry activities, teachers usually do the following:

- create a safe, stimulating environment where students feel free to explore, question, digress, and communicate;
- ask questions that require thinking and thoughtful responses or action on the part of students;
- listen to what students say and respond in ways that encourage students to examine and investigate ideas, questions, and suppositions;
- promote multiple and creative ideas for researchable questions as well as ways to conduct investigations; and
- develop classroom characteristics that place value on student communication, diversity, individuality, and intellectual freedom.

In our view, in the most ideal classroom, rather than learning *about* inquiry, students learn *through* inquiry. They apply the processes of inquiry to problems, devise ways to obtain and analyze data, and discuss the meaning of their data and experiences. Finally, students communicate their findings and ideas with others. This is true inquiry.

**Real inquiry**

*Initiating the inquiry*

The following inquiry activity takes place in a biology class but would be appropriate for a physics or physiology class as well. It is offered here as an example of how a common, tried-and-true activity can be modified to facilitate inquiry.

A biology teacher holds the end of a crisp, new dollar bill so that it hangs vertically. She then asks if any students think they can catch the bill between their thumb and forefinger if she drops it from this position. Students must be holding these two fingers apart on either side of the bill at its center, ready to catch it by closing their fingers. Several students think they can and give it a try, but to their surprise, none of them are able to catch the dollar.

The teacher then asks students about the process of trying to catch the bill. Students often reply that they see it start to fall and then try to close their fingers in time to catch it. With some probing, they find that when the dropping bill is recorded on the retina, a signal is sent down the optic nerve to the brain, and the brain then sends a command down the spinal column, out the arm, and to the hand. At this point, the hand muscles close in an attempt to capture the bill.

Students are intrigued when they realize that catching the bill involves more than originally assumed. With this in mind, the teacher can ask, “What must happen in order for you to see the bill drop and then catch it?” After a discussion of the various nervous pathways, the teacher might then ask, “If the path through the eye were complicated, what other senses could you use to catch it?” After a bit of brainstorming, students usually suggest other tests they can perform. For example, the catcher closes his or her eyes. He or she then tries to catch the bill when tapped on the shoulder as the bill is dropped, or when someone says “Drop!”

After thinking through the possibilities with their fellow students, most predict that they can catch the bill more easily by seeing the bill drop, while some think that touching or hearing may be more powerful senses. An inquiry-oriented teacher encourages all alternate suggestions and directs students to work in small groups, design and carry out procedures that address these questions, and then share their results.

Before students break into groups, however, the teacher must first teach them the skills they need to be successful in this activity. In this case, students need a more quantitative approach to accurately compare. The teacher might then ask, “How can we make this experiment more quantitative?” With minimal guidance, students usually figure out that they can use metersticks instead of a dollar bill. Again, students should be involved in developing the techniques they use for data collection. A brief discussion about techniques for collecting data with the meterstick takes place, and students consider the need to standardize methods in order to compare...
results and compile class data. For instance, students might agree on a number of controlled variables, such as the catcher’s forearm should be held horizontally, both partners need to be standing, and a certain number of trials should be completed (and averaged).

After brainstorming and a discussion, students might establish directions similar to the following: “Have your partner (the ‘dropper’) hold the top end of a meterstick at approximately the 90 cm mark and place your thumb and first finger at approximately the 10 cm mark, about 1 cm apart from the ruler. When you receive the cue, try to catch the ruler between your fingers as quickly as you can and note the distance it takes to catch the stick.” Following a quick demonstration of the student-designed procedure, the class will likely need a short discussion about converting distance to time so that all students are ready to design their own experiments and collect data (see “Searching for answers”).

**Searching for answers**

With a research question, hypothesis, and procedure in place, students are then ready to collect data, or in this case, test their reaction time under three variables:

- sight (seeing the meterstick being dropped),
- touch (having the shoulder touched as the stick is dropped), and
- sound (hearing “Drop!” as the stick is dropped).

After performing the procedure, students find the distance from the 10 cm point to where the meterstick is caught. Most try the procedure multiple times, averaging the distances for each of the three modes. As groups share results with the rest of the class, students are surprised that catching the ruler appears to be quickest through the touch method.

A class discussion incorporates anatomical drawings and briefly reviews the neural pathways for sensory and response actions that occur when catching the ruler. Explanations for these results are also discussed, including a consideration of energy transformations and the differences among light, sound, and touch. The teacher then invites students to calculate their own response times for each of the modes. To do this, they collect distance data from each attempt to catch the dropping meterstick and interpolate from a graph of acceleration due to gravity that lists “distance” in centimeters along the x axis and “time” in milliseconds on the y axis.

A more mathematical calculation that integrates physics into the activity can be done using the equation for acceleration due to gravity and solving for time. Students must pay close attention to units of measurement with this method. They can determine their reaction time by using the formula $d = \frac{1}{2} gt^2$, where $d$ is the distance (in meters) the meterstick falls before being caught, $g$ is the acceleration due to gravity (9.8 m/s$^2$), $t$ is the time in seconds, and air resistance is assumed to be negligible. For example, if the meterstick falls 15 cm before being caught, the student’s reaction time is approximately 0.18 seconds (180 milliseconds).

**Evaluating results**

Once students have conducted multiple trials and collected data, results are compared and further anatomical and physiological explanations are considered to explain why the times are different for each mode. Group data are collected for each individual’s quickest mode and explanations are considered for why everyone’s data are not the same. The effect of unique student experiences and training, such as being a piano player versus a long distance runner, may be considered.

After measuring the distance from the edge to the center of the dollar bill and examining the acceleration graph, students extrapolate the reaction time necessary to catch the dollar. Explanations are sought as to why it is almost impossible to do so. Since a dollar bill is 15.6 cm in length, students can be asked to calculate the reaction time necessary to catch it, holding their thumb and forefinger at about halfway (8 cm). (Answer: about 130 milliseconds.) The teacher can also invite students to offer hypotheses that test the effect of touching the body in places other than the shoulder that are different distances from the spinal cord—including opportunities to discuss the nervous system.

From this inquiry investigation, students discover their own response times for each of the three modes and compare
them to other students. Through some initial learning of anatomy and physiology concepts, students construct tentative reasons for their observations of the different modes, especially when the pathway includes different kinds of energy, which may have different transmission speeds. They also learn that by engaging in the process of scientific inquiry, they can find answers to interesting questions. As an added benefit, this level of active engagement has been shown to reduce student restlessness and classroom management problems (Leonard, Speziale, and Penick 2001).

Additional inquiry activities can also be investigated. Does talking on a cell phone or listening to music affect reaction time? Does reaction time improve with practice? Is reaction time different at different times of the day? Do piano players have faster-than-average reaction times? Each of these questions can be used to facilitate student inquiry activities.

Unreal inquiry

Some activities or curriculum claim to be inquiry, but in reality, are not. The following are examples from science curricula that claim to use learning by inquiry—but fail to do so.

- This appears in a section of a biology textbook labeled “Doing an Inquiry”: Prepare a slide of an onion cell by peeling off the lower layer of the onion section. Place it on a glass slide and add a drop of water and a cover slip. Notice the position of the cell membrane relative to the rest of the cell contents. Add a drop of salt water and observe. What do you see? Provide an explanation. Draw the cell before and after adding the salt water.

  This may be an example of active learning, but it is not learning through inquiry because most of the requirements of inquiry listed previously, such as posing a research question, are absent. Rather, this is rote, cookbook learning.

- This appears in a section of another biology textbook labeled “An Inquiry Investigation”: Design an experiment that shows that the intensity of light affects the rate of photosynthesis in Elodea.

  Not only does this example not meet the previously discussed characteristics of inquiry learning, but there is also no requirement that students actually do the experiment; this is a passive mental exercise only, at best. Moreover, the instructions even suggest what the results may be, so this is simply a verification activity and not true inquiry.

Learning how to do scientific inquiry is the objective. Students conduct an empirical search for answers to questions by designing procedures, collecting and analyzing data, seeking evidence and confirmation for the proposed ideas and answers to the questions, and communicating results. Clearly, these two examples would not meet the stated criteria of any of the multiple E models of inquiry (see “More on inquiry”).

Conclusion

As a teacher, you can routinely check to see that your students are actively learning through inquiry by comparing what is occurring in your classroom to the student and teacher actions noted in the beginning of this article. Are students thinking, making decisions, structuring at least some portions of the investigation, collecting and analyzing data, and considering new ways to make the investigation better? If they are, then you and your students are on the road to additional success with science learning and motivation.

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References


