Inquiring Scientists Want to Know

By prompting students to come up with their own answers, inquiry-based instruction leads to a deeper understanding of scientific concepts.

Alan Colburn

Critics have often accused the teaching field of faddishness. New ideas come and go, cynics say. But inquiry-based instruction is a clear exception. This teaching practice, which encourages students to learn inductively with the help of real-world exemplars, has a firmly established place in pedagogical tradition. For hundreds of years, educators and theorists—Johann Heinrich Pestalozzi and Herbert Spencer among them—have championed student learning through concrete experiences and observation rather than rote memorization (DeBoer, 1991).

Today, we use a variety of terms to refer to this general concept—such as student-centered or constructivist learning—and we apply the practice across the content areas. In science, inquiry-based instruction is founded on several assumptions:

- Learning to think independently and scientifically is a worthy instructional goal.
- Learning to think independently means that students must actually think independently. Critical thinking is a complex skill that requires instruction, practice, and feedback.
- Thinking is not a context-free activity. To gain a deep understanding of scientific concepts, learners must actively grapple with the content. In addition, students must be developmentally ready to understand the content and possess the requisite sophisticated thinking skills to comprehend a given scientific idea. Teachers must choose activities that match students' background knowledge and reasoning skills.

Why Inquiry-Based Teaching?

Why is inquiry-based instruction such a good way to teach science? And what distinguishes it from other teaching practices? To illustrate the difference, let's look at a science concept familiar to anyone who has left fresh food to molder on a countertop: Warm, moist environments tend to be conducive to the rapid growth of fungi. Cold, dry environments tend to slow fungi growth. How might students gain an understanding of this idea?
**The Verification Approach**

One classic, non-inquiry-based way of teaching students about this concept involves a laboratory manual detailing an experiment entitled "Factors Affecting Fungal Growth." The manual introduces the lab activity with some background information and a sentence or two about the activity's purpose. Perhaps the introduction even tells students the "right answer"—that is, the expected outcome for the activity: "This experiment demonstrates that molds grow more quickly in dark, moist environments than in light, dry ones."

After reading the introduction, students follow the procedure section step-by-step. The manual instructs the students to put four pieces of white bread in individual zip-lock bags and then to place one bag in a refrigerator, one in an incubator, one on a sunny windowsill, and one in a dark cabinet. Following the procedure section, students fill in the manual's blank data tables with their specific observations (already outlined in the procedure section). Finally, students answer the manual's questions about what they were supposed to have learned in the activity.

Such an activity could be worthwhile as a demonstration or as a practice session for students to hone their lab skills. As a way for students to learn to think independently, however, the activity is considerably less effective. The manual spells out everything for the students—the question to investigate, the procedure to address the question, the kind of data to collect, and even the meaning of the data. All students need to do is verify the facts that they have already been fed.

**The Discovery Approach**

One response to this step-by-step "cookbook" approach to teaching is a practice known as discovery learning. Largely triggered by the perceived threat of Soviet scientific supremacy in the 1960s, this U.S. curriculum reform effort aimed to teach students to think like scientists through inquiry and active involvement in the lesson. Today, the phrase often has a negative connotation. Still, this inductive approach to learning is based on a simple and worthy idea: The ideas we tend to retain are those we create for ourselves.

A good example of discovery learning is the Elementary Science Study, a National Science Foundation-funded program that brought hands-on science learning to K–8 students throughout the United States in the 1960s and 1970s. Students in the study's classrooms typically worked on open-ended, exploratory lab activities, guided only by a handful of questions and some materials from their teachers. Research (Shymansky, Hedges, & Woodworth, 1990; Shymansky, Kyle, & Alport, 1983) indicated that students taught with curriculums like the Elementary Science Study liked science more and were better at "doing science" than peers taught with other curriculums.

Much as students enjoyed these curriculums, however, critics claimed that discovery-based curriculums were cumbersome and placed unrealistic demands on teachers to understand an extremely wide range of science content—an especially unreasonable prerequisite for generalist elementary teachers. Critics also contended that having students "discover" all major science concepts was unrealistic and counterproductive.
**The Inquiry-Based Approach**

Inquiry-based instruction represents a realistic middle ground between the extremes of verification activities and discovery learning. These days, educators almost universally advocate inquiry-based instruction, as demonstrated in the National Research Council's *National Science Education Standards* (1996) and in the American Association for the Advancement of Science's *Benchmarks for Science Literacy* (1993).

Inquiry-based instruction represents a broad range of instructional possibilities. At one end of the spectrum, students make few independent decisions; at the other end, students make almost all the decisions. Because the term is somewhat imprecise, science educators commonly refer to three different kinds of inquiry-based instruction: structured inquiry, guided inquiry, and open inquiry. Herron (1971) and Schwab (1964) conceptualized inquiry-based instruction in terms of who is making decisions about various aspects of a laboratory activity. Does the teacher or student decide

- The question to investigate?
- The procedures to follow in addressing the question?
- The data to collect and analyze?

**Structured inquiry.** A structured inquiry version of the bread mold lab activity looks similar to the verification approach. The teacher or lab manual might give students step-by-step instructions but does not necessarily provide a ready-made data table. Students must decide for themselves what observations are most important to record and must figure out, to some extent, the meaning of their data.

**Guided inquiry.** In the guided inquiry version of the lab activity, students not only choose what data to record and interpret the meaning of that data—as in structured inquiry activities—but they also design the procedure that will address the activity's main question. The teacher might simply distribute the lab materials to students and instruct the students to investigate whether or not light and temperature affect fungal growth on bread. Consequently, students' procedures, results, and interpretations in guided inquiry activities often vary. Such variations spark lively classroom discussions that lead to a deeper understanding of the content.

**Open inquiry.** In an open inquiry activity, students make almost all the decisions. A scientist conducting independent research and a student completing a science fair project are both practicing open inquiry. In the quintessential open inquiry activity, a student thinks of a question to investigate, considers how to investigate the question and what data to collect, and decides how to interpret that data. The bread mold activity would approach open inquiry if the teacher simply told students to investigate factors affecting fungal growth, with little or no additional guidance.

**Challenges of Inquiry-Based Instruction**

Inquiry-based teaching practices can present teachers with a number of challenges. Problems surface because students in many classrooms are not used to figuring out so much on their own and may wonder why teachers won't simply tell them the right answers. Students may
also require different background skills and knowledge. In addition, some parents, administrators, and teachers don't fully understand the value of inquiry-based instruction.

The challenges of implementing inquiry-based instruction yield no quick fixes. Just as a ramp makes it easier to lift a heavy load, teachers may find it easier to make the transition to inquiry-based instruction by implementing changes gradually. A teacher accustomed to students performing verification lab activities can gear the activities toward structured inquiry with just a few small changes. In the mold experiment, the teacher could remove the data table, conduct a preliminary classroom discussion to point students in the right direction, and, after the experiment, ask students to share information about the variety and significance of the data that they collected.

Once the teacher and students are comfortable with these activities, the teacher can begin shifting instruction toward guided and open inquiry by continuing to remove the supports of the activity. For example, if an activity's directions tell students to pour 10 milliliters of liquid in a medium-sized test tube, the teacher can instead direct the students to pour "a little" liquid in the tube. Students will inevitably place a variety of volumes in their test tubes—from almost none to a full tube's worth. Consequently, results may vary—prompting great possibilities for class discussion on how and why the results varied as they did.

Extension activities in lab manuals can also be a good source of guided inquiry activities. Students' completion of the manual's verification or structured inquiry activity will only increase their chances of success in the guided inquiry extension activity (Colburn, 1997; Colburn & Clough, 1997).

**The Role of Assessment**

Both during and after this transition period, assessment is crucial. Continual formative assessment of student understanding through observation, student questioning, and written assignments helps teachers decide how well students are doing—when it's time to move on to more open-ended activities and when it's time to backtrack and scaffold student understanding. Assessment also tells students what is really important. If the teacher assesses students solely on the basis of factual recall, then students learn that factual recall is the class's central goal. Teachers' assessments in inquiry-based classrooms must stress scientific reasoning and critical thinking in addition to content knowledge. For the mold activity, for example, a teacher could assess students' abilities to

- **Generate open-ended, researchable queries.** Extend on the experiment by having students develop further questions to investigate after interpreting the data from the mold activity.

- **Devise scientific procedures.** Have students come up with a procedure to address a question and situation similar to the mold question already investigated.

- **Interpret data.** Provide students with sample data from a given scenario and ask them to analyze the data's meaning and implications.

Most of these problems are closer to essay questions than short-answer or multiple-choice
questions, and they can increase teachers' grading time. Adding one or two essay questions to an array of short-answer items, however, is still realistic and doable, even in crowded classrooms. It is also crucial. Teachers advocating inquiry-based teaching must evaluate students on goals congruent with the instructional approach.

Educators have long created successful schools and classrooms with relatively unstructured, hands-on instructional climates. Deeply rooted in best practices, inquiry-based teaching is designed to help students learn to think independently and gain problem-solving skills that will help them throughout life. After all, teaching students to raise questions and find answers for themselves is the whole aim of science instruction. As citizens, we want to know that the students who receive high grades in science have the abilities required for independent thought and success in later life.

References


---

Alan Colburn is Associate Professor of Science Education at California State University, 1250 Bellflower Blvd., Long Beach, CA 90840; 562-985-5948; acolburn@csulb.edu.