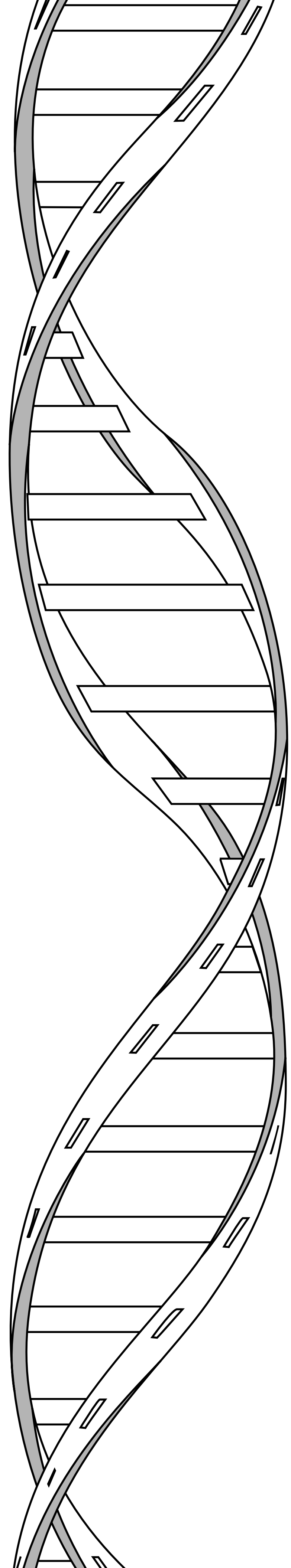
Chapter 1

Introduction



What exactly does inquiry mean? What is standards-based science teaching? What is the constructivist approach? And, why should we include these ideas in our lesson designs? This first chapter addresses these basic questions with an overview of the theory on which the book's lessons are based. The term *inquiry* has assumed many faces in education. The chapter describes the different forms of inquiry distinguished in the *National Science Education Standards*. Constructivism is introduced and a list of more detailed resources for these topics is provided.

What Is Standards-Based Teaching?

THE *NATIONAL SCIENCE EDUCATION STANDARDS* (the *Standards*) was published by the National Research Council (NRC). The *Standards* was developed over four years with input from tens of thousands of scientists and educators. The work is not a curriculum. That is, it does not provide lists of content topics that should be mastered in the way that many state standards do. The life science content standards, for example, focus on general themes that should be emphasized by teachers, such as the molecular basis of heredity. The national standards are a broad guide, a vision, for effective science education. They offer research-supported prescriptions for how best to develop scientifically literate students.

Standards-based teaching mobilizes the vision of the *Standards*. It employs strategies derived from learning theory research such as constructivism. It is steeped in inquiry. It strives for deep understanding of science content over superficial memorization of facts.

The *National Science Education Standards* are available for purchase in print or for free online from National Academy Press. Leonard, Penick, and Douglas (2002) offer a useful twenty-point checklist and rubric for teachers to self evaluate the extent to which they are standards-based.

Inquiry

The chorus from the acronymed science and science education organizations (AAAS, NRC, NSTA, NABT, BSCS) coalesces around the primacy of inquiry. The *Standards* advise that science teachers should employ varied strategies, but inquiry is clearly positioned as the central approach in the document. In fact, the NRC even published a separate volume focusing solely on inquiry in the science classroom (NRC, 2000). The *Standards* define inquiry as:

> *A multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)*

The National Science Teachers Association position statement on scientific inquiry (2004) proclaims that "understanding science content is significantly enhanced when ideas are anchored to inquiry experiences." They recommend that all K-12 teachers make inquiry the centerpiece of the science classroom.

Scientific Inquiry Versus Inquiry Learning

An important distinction is carved in the *Standards* between the type of inquiry practiced by scientists and inquiry as an approach to teaching science content in the classroom. However, both are essential components of a science curriculum. Scientific inquiry refers to designing and conducting scientific investigations. According to the *Standards,* students should learn how to do scientific inquiry (abilities) and to comprehend how science is done (understandings). In essence, scientific inquiry should be taught as both process and content in a biology class. But "abilities necessary to do scientific inquiry" means more than just the science process skills that are traditionally taught such as observing, measuring, and experimenting. The *Standards* promote a more complete integration of science process skills with the evaluation, interpretation and explanation of data (NRC, 2000).

On the other hand, inquiry in the *Standards* also refers to a classroom strategy for teaching any other science content such as photosynthesis or molecular biology. Such an inquiry approach involves the learning of concepts through inquiry investigations. For example, students might discover for themselves in an inquiry that plants respire by collecting and evaluating data showing a net oxygen consumption in the absence of light.

It is clear that the *Standards* aim to move teachers away from the traditional stand-alone "scientific method" or "science process" unit that often initiates a course. Instead, science inquiry abilities should be developed continually throughout a course and in the context of new biology content learning.

Inquiry Learning Defined

The NRC (2000) provides and explains a working definition of an inquiry approach to teaching science. Their definition centers on "Five Essential Features of Classroom Inquiry." (Bybee, 2002) summarizes the five essential features as:

1. Learners engage in scientifically oriented questions.
2. Learners give priority to evidence in responding to questions.
3. Learners formulate explanations from evidence.
4. Learners connect explanations to scientific knowledge.
5. Learners communicate and justify explanations.

As much as possible each of these features is pursued by students with significant input and sometimes self-initiation. Traditional cookbook labs and activities do not achieve these features. Typically such labs provide the student with a scientific question, an introduction that answers the question, a step-by-step procedure and directions on how to analyze the data and explain the results. Inquiries, on the other hand, begin with questions that may be developed or refined by students. Then they often require students to devise ways to answer the questions. Learners collect and interpret data, using it as evidence to support new understandings. Content learning then occurs as students evaluate their data in the context of scientific knowledge gleaned from book, teacher, or Web resources. Finally, scientific explanations are proposed, debated, and defended by learners. Volkmann and Abell (2003) offer an "inquiry analysis tool" to assess whether a lab activity includes the essential features of inquiry.

In general, inquiries involve less pre-lab than found in cookbook activities. First, students are not presented with the ideas to be learned in the beginning of the lesson. Instead they develop understanding of the concepts throughout the experience—and especially toward the end. New terminology is introduced after exploration. Second, there usually is not a long explanation of a procedure before an inquiry lab because students are more involved in developing the investigative approach themselves during the activity. Inquiry labs often begin with just a brief introduction to some possible materials, important safety notes, and sometimes a brief demonstration of relevant equipment or a data-collecting approach.

Partial Versus Full Inquiries

Inquiry learning activities that consist of all five of the "essential features" are considered *full inquiries*. *Partial inquiries* include only some of the five features. A partial inquiry might, for instance, provide experimental data for learners to manipulate, analyze, and explain. Both types of activities have value for the biology classroom. Partial inquiries can address a specific science process ability. They can form part of a sequence of experiences that together include all five features of inquiry. But many full inquiries should be used throughout a biology course.

Open Versus Guided Inquiry

Inquiries vary in the balance between student self-direction and teacher guidance. The NRC (2000) recommends that inquiries of different degrees of "openness" be employed by teachers. Specific biology content concepts are probably best taught through more structured, guided inquiries that focus learners on the intended outcomes. After all, students can't be expected to rediscover hundreds of years of biological knowledge through self-initiated questions. And some starting information or guidance is often necessary to raise the inquiry to higher levels. More open inquiries better develop scientific investigation abilities. These focus more on learning to do biological research than learning a specific biology concept. Clark, Clough, and Berg (2000) address this issue well:

> *In rethinking laboratory activities, too often a false dichotomy is presented to teachers that students must either passively follow a cookbook laboratory procedure or, at the other extreme, investigate a question of their own choosing. These extremes miss the large and fertile middle ground that is typically more pedagogically sound than either end of the continuum. (p. 40)*

In Investigating Osmosis in Plant Cells the prime objective is developing understanding of osmosis in plants. So the learners are given a teacher-initiated question to investigate. They experience the five essential features of inquiry, and they delve deeply into osmosis. On the other hand, Investigating Plant Growth is a more open inquiry in which learners choose their own questions to investigate. With groups investigating different variables, the biology concept learning varies across the class. But all students experience scientific inquiry from beginning to end and at a depth that isn't possible in the osmosis example. Termite Trails Mystery exemplifies an inquiry in which students initially explore their own questions, but then discussion guides the group toward investigating one central topic.

Initiating Inquiry: Discrepant Events

Inquiry begins with questions. Sometimes questions are offered by the teacher and students are challenged to develop a means of finding answers and explanations. Or questions can be generated by students out of previous learning, readings, discussions, or explorations. One way to jump-start the inquiry process involves discrepant events. An occurrence that is discrepant to students is one that is contrary or inconsistent with what they were expecting. In Termite Trails Mystery, for example, a termite dropped onto paper begins to follow a red ink trail. This is strange and unexpected to the students. Discrepant events pique student curiosity. They capture attention and, most importantly, they motivate students to learn more about the observed occurrence. With a mystery to be solved, learners are primed for inquiry. They have a reason to design, conduct, and interpret experiments. They have a purpose for using books and Web resources to acquire scientific knowledge. Other lessons involving discrepant events include Red Dot Special, What Is Life? Glue Goblins, Mendel's Data, Cold-Blooded Thermometers, and Water Discrepancies.

Converting Cookbook Labs to Inquiry

Developing an inquiry-based classroom does not have to require reinventing the wheel. Many traditional labs and activities can fairly easily be modified into inquiry experiences. Generally, this involves simply reversing the organization of the lesson. Instead of concepts first followed by an "experiment" to verify the concepts, reposition the investigative part to the beginning. Begin with questions. Then students collect and interpret data. Eventually students are exposed to the concepts via teacher, book, or Web resources. They then further develop understanding by evaluating their lab experiences and data in light of accepted scientific knowledge.

The content information is back-loaded in an inquiry. It follows a period of seeking explanations for mysteries, solutions to challenges, and approaches to explorations. This is similar to watching a baseball game in that students are much more excited when the outcome is unknown than they would be in watching a replay (Alberts, 2000).

In a modified cookbook lab, the procedure is either deleted or greatly reduced. Instead of a step-by-step recipe, students may be presented with some general guidelines or suggested approaches. The use of a new data-collecting tool might be explained. Some possible materials to use may (or may not) be listed. Students create their own experimental designs. Each lab group in a class may develop a different approach to exploring the topic of the lab.

Investigating Osmosis in Plant Cells and The Osmosis Inquiry Egg are examples of classic labs that were modified into inquiries. Llewellyn (2002) and Clark (2000) offer many useful strategies for converting labs into inquiries.

Questioning in an Inquiry Classroom

Questioning comprises the core of inquiry. Often, students generate questions to investigate. They question their own ideas and those of their classmates. And teachers continually question students to find out what they know and to challenge them to think. In an inquiry-oriented classroom, teacher questions go well beyond asking for recall of facts. Instead, questions intend to draw students out, to prompt learners to develop an understanding of concepts. For real learning to occur, students have to be held accountable for being engaged. Inquiry questions don't let the recipient off the hook—they require the student to explain, to analyze, to justify.

The following list contains examples of responses and questions frequently heard in inquiry-oriented classrooms:

- Good question. What do *you* think? (as a typical response to students' questions)
- Interesting. Why do you think that?
- Interesting idea. How could you test that?
- Interesting idea. What evidence do you have for it?
- Is there another possible explanation for that?
- What kinds of data could help answer that question?
- What can you conclude from that?
- How do you explain these observations/data/results?
- What are some hypotheses for that?
- What information would you need to research before investigating that topic?
- How confident are you of these results? Why?
- What else could have led to these experimental results?
- What are the variables in this experiment?
- What are the constants in this experiment?
- What further questions are raised by these results/conclusions?
- Good start. How could we improve on that idea?
- What can you now conclude about your hypothesis?
- How do you justify your conclusion/explanation?

- How could that experiment be made even better?
- What will that experiment tell you? How will it do that?
- What kind of data will you collect? Why?
- Can you think of any other data that would provide even more information?
- What mathematical analysis can you do to your data to get more information out of it?
- Does everyone agree with that statement/conclusion/reasoning?
- Who has some constructive feedback for this group?

"The Lab Didn't Work"

An attraction of cookbook labs for teachers is their predictable, consistent results. Students as well as teachers become molded to the lab experience where everyone knows the expected lab result and most groups either get that result or fudge their data to look like they did! If students don't achieve the expected, they conclude that either "the lab didn't work" or they "messed up." But with inquiries there is not usually one right answer or outcome. Instead, the emphasis is on "What results did you get and how do you explain them (whether expected or not)?"

True, the inquiry-oriented lab atmosphere can seem messy at times for student and teacher. But if it all leads to serious thinking about the biology concepts and scientific process, then the experience is successful no matter how messy. Let's look at an example. In The Osmosis Inquiry Egg students investigating salt as a variable often very reasonably predict that an egg in salt water will lose mass. But even in very salty (20 percent) solutions, the eggs do not lose mass. I have had students observe such results and proclaim, "It didn't work" or "We messed up" or, the best of all, "The egg is messed up." I lead them away from this sort of thinking with a short discussion. I ask if those are the only possible explanations they can think of. I emphasize that data is data. Their task is to explain the data they got. It is critical to emphasize to the students that they will not be penalized for getting "strange data" or for missing "the right" explanation. They need to focus on developing logical explanations. A sincere and complete effort at this is what matters.

In the case of the egg in salt water, maybe the egg is hypertonic to the solution. Or maybe the salt didn't completely go into solution. Or maybe the membrane is permeable to salt. I don't know the exact answer, *but that doesn't matter.* What matters is students doing what scientists do—using their minds to develop possible explanations, alternative explanations, and justifications with a combination of logic and biological knowledge. Students may actually learn more about a topic like osmosis when they have to explain surprising results.

Assessing Inquiry Investigations

Assessment takes many forms and serves many purposes in the science classroom. Two books that explore the subject in detail are *Classroom Management and the National Science Education Standards* by the NRC (2001) and *Science Educator's Guide to Laboratory*

Assessment by Doran, Chan, Tamir, and Lenhart (2002). The following provides just a few suggestions for assessments to follow an inquiry lab after a brief overview of the topic.

Three types of assessment occur in the inquiry-based, constructivist classroom. They provide feedback to students that helps them to further develop understanding.

1. Diagnostic Assessment

These inform the teacher (and students) of learners' prior knowledge. What do they know? What preconceptions and misconceptions do they have? These assessments are never graded. Their purpose is to determine where the students are so the teacher can decide on areas that need to be addressed. They also help students to clearly identify their own preconceptions so that they can specifically compare them to new experiences and explanations. Many of the entries in this book begin with questions and discussions to assess prior knowledge. Also, strategies such as concept maps, drawings, Venn diagrams, and others can be used. Prior knowledge assessment is critical for a constructivist approach to teaching.

2. Formative Assessment

Formative assessments occur frequently. They are informal and usually not graded. Formative assessment provides feedback to students. It helps them further their understanding of skills or concepts. It takes the form of questioning, discussing, critiquing, peer critiquing, self-critiquing, and other techniques.

Formative assessment is assessment in that it gauges student abilities and understandings but it is teaching in that it also helps the student to improve those abilities and understandings. All of the lessons in this book include questions, discussions, feedback sessions, and reflections that serve as formative assessment.

3. Summative Assessment

Summative assessments occur at the end of an activity, unit of study, or course. Tests, lab reports, and other graded assessments fall in this category. A summative assessment attempts to quantify the level of student achievement. What did they learn? What do they now know or know how to do? How well can they explain certain concepts? There is, of course, overlap among the types of assessment. For instance, many summative tasks can also involve a formative component or be used in a formative way.

Scientific Reporting

Central to scientific inquiry is the communication of goals, procedures, experimental approaches, results, and explanations. There are a number of ways that students can report on their investigations. These develop scientific reporting abilities and inform the teacher of student achievement.

Lab reports are an important format for communicating scientific information that students should experience. However, scientists communicate their results in many other ways as well. And student interest is heightened if a variety of strategies for assessing labs are used.

Mini posters (Williamson, 2002) are used by students to create a scaled-down version of a scientific poster like the ones used by researchers at conferences. By taping or gluing two file folders together, they make a three-paneled, self-standing mini poster on which they present information on their investigation (see Figure 1.1). On the due date students set up their mini posters, and they circulate among those of others, reviewing and critiquing them. The posters fold into an 8–1/2 x 11-inch size for storage. If a section (or more) of the mini poster is deemed to need revision, it is easy for a student to rework that section only and then tape it on top of the original version of the section. An advantage to the small poster size is that it forces students to be concise. See the outline in Worksheet 1.1 for the sections that could be included in a mini poster or scientific lab report paper. Worksheet 1.1 could also be used as a handout for reference.

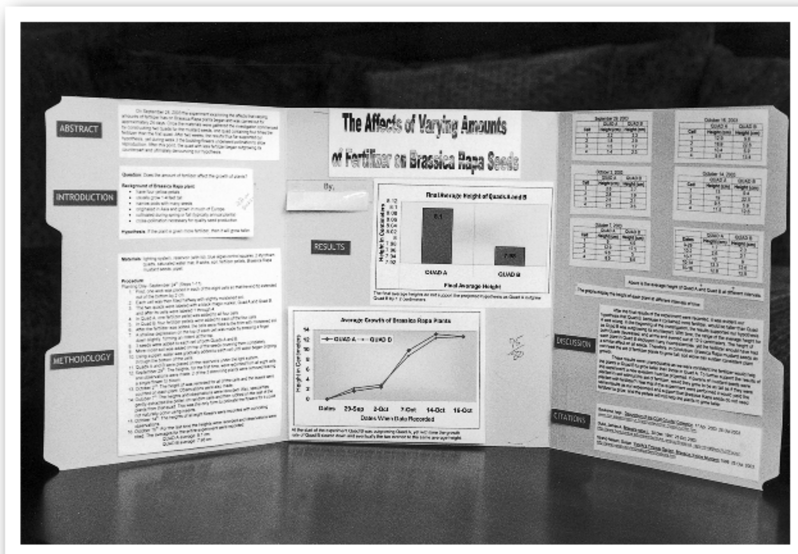


Figure 1.1. Example of a Miniposter

Oral presentations can take many forms. Students can use posters, overhead transparences, PowerPoint® slides, and so on. Often inquiry investigations lead different student groups in different experimental directions, so presentations promote concept learning among the audience as they learn about an investigation that is different from their own. Presentations also allow for modeling of skills, abilities, and approaches. Students observing exceptional presentations learn what "could have been done" and the achievement bar is raised for all.

More importantly, oral presentations facilitate formative feedback discussions that advance understanding for everyone in the class. During or after presentations the teacher questions presenters and/or audience members about statements made, experimental design flaws, faulty logic, content misconceptions, and so forth. The teacher should also encourage peer critiquing. Productive questions include, "Does anybody see a flaw in the experimental design?" or "Does everyone agree with that statement/claim/conclusion?" or "What else could have been done?"

Reflections encourage students throughout an investigation to think about what they are doing. In class or at home journal writing encourages student thinking on questions, experimental designs, conclusions, and biology concept explanations and applications. These are ongoing formative assessments. They aid the learners in constructing new understanding for themselves.

Narrative lab reports (Licata, 1999) are a periodic alternative to formal lab reports that focus students more on the concepts than on the structure of the reporting. In a continuous essay, students "tell the story" of the inquiry. They can be focused on addressing central questions such as:

- What was I looking for?
- How did I look for it?
- What did I find?
- What does this mean?

Data tables, graphs, sketches, and *calculations* can be embedded in the body of the essay or added to the end. Either way they should be discussed in the narrative.

Name ______________________ Date ______________________

WORKSHEET 1.1

Sections for a Scientific Paper or Poster

I. The Title

The title should be descriptive. It should be brief *but* it should also indicate the variable(s) that were tested. A poor title: *Plant Experiment.* A better one: *Investigation of the Effects of Mozart's Music on* Brassica rapa *growth.*

II. The Abstract

A one- or two-paragraph summary. The abstract condenses the entire report into a brief, clear, quickly readable overview.

III. Introduction

Background information: What is the experimental topic? What is known about the topic? What is unknown? How does this study fit into that context? Define and explain the major scientific concepts.

Questions and hypothesis: Explicitly state the experimental question being investigated. State any hypotheses being investigated and if/then predictions.

IV. Methods and Materials

Procedure: Listed numbered steps. What exactly was done (written in past tense) in enough detail so others could replicate your experiment. But keep it concise.

Materials: What materials were used?

Statistical/mathematical analysis: What calculations (for example, mean of height increase in plants exposed to. . .) were made?

V. Results

1. Data tables and graphs go here.
2. Describe the results but do not interpret them here. Interpretation of results goes in "Discussion."

VI. Discussion

Address the original question and hypothesis. Did the experiment answer the question? Did the results support the hypothesis? *Refer to the data* to back up conclusions.

Explain the data. If the results were unexpected, why were they? Even if results were expected, what other possible explanations are there?

Biological meaning, implications, context, and "big picture." Any generalizations and new predictions can be described here.

Areas of future research should be described.

VII. Literature Cited

Bibliography of all sources used for background information.

Adapted from: Ambrose, H., Ambrose, K., Emlen, D., & Bright, K. (2002). *A handbook of biological investigations* (6th ed.). Winston-Salem, NC: Hunter Textbooks.

Constructivism

A growing body of evidence supports the infusion of constructivist learning theory into science lessons. Central to constructivism is the notion that humans actively construct knowledge based on interactions with the physical world and social interactions with others. Learning does not happen by receiving information. Rather it occurs as people actively build new understandings for themselves. Also, people enter learning opportunities with pre-existing understandings that were constructed through previous experiences.

Implications for Biology Teachers

Two primary insights from constructivism need attention from biology teachers:

1. Knowledge is actively constructed by learners. Our students are ultimately responsible for developing their own new comprehension. Lasting learning will not occur via an active teacher transmitting information to passive recipients. Teachers instead need to guide students through the process of constructing new knowledge for themselves.
2. Students come to class with previously constructed knowledge based on their past experiences. These preconceptions, many of which are misconceptions, are hard to displace! Research shows that unless students acknowledge and address their preconceptions on concepts studied in class they do not abandon them (NSTA, 2003).

Constructivist Lessons

Some of the essential aspects of a constructivist lesson include:

1. *Determine student prior knowledge.* Assess students for their preconceptions on the topic(s) to be learned. This can be done via concept maps, free-association brainstorming, drawings, discussions, and so on. Many of the lessons in this book begin with discussions to elicit prior knowledge. It is critical that students not be criticized for their ideas that are misconceptions. Instead, strategies should be employed to help students recognize and decide themselves that certain prior knowledge needs to be modified or replaced.
2. *Students construct new and better understandings.* This should begin at the level of what students know and believe (preconceptions). Students engage in inquiry activities, discussions, research, and so on to build new knowledge. The process should be active, requiring much interaction, analysis, evaluation, explanation, justification, and communication.
3. *Students reflect on their learning.* If preconceptions are going to be altered or replaced, then students need to think about how new information integrates

with previously held beliefs. Via journal writing, focused questions, and discussions, learners compare where they are now to where they were before. In short, they directly address the extent to which their thinking on a subject has changed.

Trumbull (1999) points out that constructivist learning should involve dialogue, argument, and reference to evidence. Such actions help students to construct new understanding. It is also important for students to use biology content in varied situations. Such knowledge transfer facilitates deep and lasting learning.

Many of the lessons in this book follow a constructivist approach in one way or another. For instance, Are Humans Still Evolving? begins by eliciting misconceptions and finishes with students reflecting on how their thinking has changed. Bacon Diffusion exemplifies how a traditional demonstration can be modified into a constructivist introduction to a concept. A number of sources listed in the references such as Yager (1991), Llewellyn (2002), and Zelia and Geraldo (1999) go into more depth on constructivism in science education.

Questioning in Constructivist Lessons

The following are examples of teacher questions that would be supported by constructivist learning theory. Of course, all of the inquiry-oriented questions listed earlier would also fit here.

Prior Knowledge Assessment

- What do you know about . . . ?
- What comes to mind when you think of . . . ?
- What causes . . . ?
- How do you explain . . . ?

Reflection Questions

- Think back to our first discussion on this topic. Many people believed . . . . What do you now think of that idea?
- Why do you now think differently about that?
- How has your thinking on . . . . changed after this lab/activity/unit?
- How effective was your experimental plan?
- Why did we do this activity/lab/lesson? Did it help you learn? Explain.

Develop Your Own Inquiries

The *Standards,* an inquiry approach, and constructivism all point toward extended in-depth student-generated investigations. Many of the best biology learning experiences will germinate out of student interests and locally relevant issues.

Resources for Educators

In addition to the *Standards,* the National Research Council has published expanded books on inquiry (NRC, 2000) and assessment (NRC, 2001). These works are highly recommended. The National Science Teacher's Association's (2003) publication, *Pathways to the Science Standards,* helps to explain the *Standards* and provides excellent examples of each standard being implemented in the classroom.

The Biological Sciences Curriculum Study (BSCS) has promoted the inquiry approach since the 1950s. BSCS has developed a "5 E" model for implementing constructivist inquiry lessons. It provides a template for including the essential components of effective science learning. The five phases of the model are Engage, Explore, Explain, Elaborate, and Evaluate. See the BSCS Web site for much information as well as access to resources. Their Web address is www.bscs.org.

The Access Excellence Web site, www.accessexcellence.org, contains many standards-based lesson ideas, science education reform articles, discussions, and more.

Membership in NSTA provides their journal, *The Science Teacher,* which is ripe with ideas on inquiry, constructivism, and national standards. Their Web site offers many more resources at www.nsta.org. The National Association of Biology Teachers' journal, *The American Biology Teacher,* often includes inquiry-oriented ideas and discussions. Their Web site is www.nabt.org.

The Exploratorium, www.exploratorium.com, has an institute dedicated to promoting inquiry-based science learning.

References

Alberts, B. (2000). Some thoughts of a scientist on inquiry. In J. Minstrell, and E. van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 3–13). Washington, DC: American Association for the Advancement of Science.

Bybee, R. (2002). Scientific inquiry, student learning and the science curriculum. In R. Bybee (Ed.), *Learning science and the science of learning* (pp. 25–35). Arlington, VA: NSTA Press.

Clark, R., Clough, M., & Berg, C. (2000). Modifying cookbook labs. *The Science Teacher, 67*(7), 40–43.

Doran, R., Chan, F., Tamir, P., & Lenhart, C. (2002). *Science educator's guide to laboratory assessment.* Arlington, VA: NSTA Press.

Leonard, W., Penick, J., & Douglas, R. (2002). What does it mean to be standards-based? *The Science Teacher, 69*(4), 36–39.

Licata, K. (1999). Narrative lab reports. *The Science Teacher, 66*(3), 20–22.

Llewellyn, D. (2002) *Inquire within: Implementing inquiry-based science standards.* Thousand Oaks, CA: Corwin.

National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning.* Washington, DC: National Academy Press.

National Research Council. (2001). *Classroom assessment and the national science education standards.* Washington, DC: National Academy Press.

National Science Teachers Association. (2004). Position statement on scientific inquiry. Accessed at www.nsta.org.

Texley, J., & Wild, A. (Eds.). (2003). *Pathways to the science standards* (2nd ed.). Arlington, VA: NSTA Press.

Trumbull, D. (1999). *The new science teacher: Cultivating good practice.* New York: Teacher's College Press.

Yager, R. (2000). The constructivist learning model. *The Science Teacher, 67*(1), 44–45.

Volkmann, M., & Abell, S. (2003). Rethinking laboratories: tools for converting cookbook labs into inquiry. *The Science Teacher, 70*(6), 38–41.

Williamson, B. (2002). *A segment of a presentation included an explanation of the idea of using mini-posters to assess investigations.* NSTA national convention, San Diego, California.

Zelia, J., & Geraldo, A. (1999). A course for critical constructivism through action research: A case study from biology. *Research in Science and Technological Education, 17*(1), 5–17.