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To Create a World in which Children Love to Learn!

Shell Education

Effective Teaching in Today's Classroom

Teaching Science Today

2nd Edition

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Foreword by Alan McCormack

Teaching Science Today 2nd Edition

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Chapter 4

What Is Inquiry?

> "We have a hunger of the mind which asks for knowledge of all around us, and the more we gain, the more is our desire; the more we see, the more we are capable of seeing."
>
> —Maria Mitchell

Most teachers would acknowledge the idea that students need to *do* science to *learn* science. However, not all science classrooms are filled with activity, research, and hands-on experiences. Teachers may avoid implementing inquiry-based instruction in their science classrooms for many reasons. It could be that it's too time consuming, too chaotic, classrooms are ill-equipped, or that teachers may not feel comfortable enough to let students explore ideas on their own. Preparing quality inquiry lessons is typically more time consuming for teachers than traditional textbook learning. Teachers need time to set up equipment and materials, organize their classrooms, and clean up. However, the results as evidenced by student learning are powerful. An inquiry-based classroom may be busier, nosier, and (sometimes) messier than traditional classrooms. Teachers should know that inquiry can be as structured or as open-ended as they allow, or that the topic allows. Scientific investigations can require the use of expensive materials and equipment, but they don't have to. Teachers should know that it is okay for students to explore and learn on their own. Teachers shouldn't feel like they have to be talking all the time for students to learn.

Defining Inquiry

The definition of *inquiry*, according to *Merriam-Webster Collegiate Dictionary* (2005) is: *1. examination into facts or principles; 2. a request for information; 3. A systematic investigation often a matter of public interest* (646). The *National Science Education Standards* define scientific inquiry as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Scientific inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Academy of Sciences 2013, 23). In essence, inquiry is a quest for knowledge. In science, this equates to an understanding of the natural world. Pretty much everything around us has to do with the natural world. Children are naturally curious, asking questions to seek understanding: *What makes a rainbow? Why do clouds float in the air? Why does my pillow spring back after I press on it, but a marshmallow does not? Why can't I see in the dark?*

Teachers have been conducting inquiry lessons in science for generations. Still today, if one were to ask any ten teachers what is meant by *scientific inquiry*, one could expect to hear ten very different ideas and interpretations on the topic. The Next Generation Science Standards, as mentioned in Chapter 1, include three dimensions. The first of these specifically addresses the idea of scientific practices. These practices clarify what students should know and be able to do as part of conducting a scientific inquiry.

> "… part of our intent in articulating the practices in Dimension 1 is to better specify what is meant by inquiry in science and the range of cognitive, social, and physical practices that it requires. As in all inquiry-based approaches to science teaching, our expectation is that students will themselves engage in the practices and not merely learn about them secondhand. Students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves."
>
> —NGSS (2013f, 2)

If students are to "themselves engage in the practices," the role of the science teacher, then, is to provide opportunities for students to actively conduct investigations in which students actually "do" the science. This is best accomplished through inquiry. However, inquiry is more than just a set of practices. The *standards* inquiry is a step beyond the use of such skills as observation, inference, and experimentation. In addition, they require that students combine these practices with scientific knowledge (e.g., structures and properties of matter). This way, students use scientific reasoning and critical thinking to develop their understanding of the science content. The result is detailed in the Standards as performance expectations. These are the assessable statements detailing what students should know and be able to do after instruction. For example, a second-grade Next Generation Science Standard (2-PS1-1) reads "Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties" (2013g, 13). In this instance, students must engage in the practice of "doing" science by planning and conducting an experiment. Then, they must perform an action: "describe and classify materials by their properties."

Science as Inquiry

Science as inquiry is basic to science education. It is a controlling principle in the teachers' planning of student activities. The Next Generation Science Standards use the term "practices" instead of "skills." Scientific practices allow students to develop an understanding about scientific inquiry as they participate in inquiry lessons. The standards are written as performance expectations. One part of these expectations is the practice of "doing" science. For example, students cannot demonstrate their proficiency in being able to analyze data without actually analyzing data. Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and to develop the ability to think and act in ways associated with inquiry. This includes asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. The science as inquiry standards are described in terms of activities resulting in student development of certain abilities and in terms of student understanding of inquiry. However, inquiry comes in many shapes and sizes, as explained in the following sections.

Confirmation Level Inquiry

Many "inquiry-based" activities that teachers may find online or in other resources are far from being true inquiries. Teacher demonstrations, although they do support inquiry-based instruction, are common activities. These types of inquiries generally confirm a scientific principle. Therefore, they are often referred to as *confirmation-level inquiries*. With a teacher demonstration, the teacher has one set of materials and equipment. He or she stands at the front of the class and walks students through the process of investigating. For example, to introduce the concept of sound energy, the teacher may bang on a pan close to a pile of rice placed on wax paper. The rice, responding to the sound energy created by the banging, jumps and moves. In this demonstration, the teacher is running the show entirely. The teacher sets up the situation, conducts the activity, and poses the questions. All the students do is watch and talk (and maybe write predictions or summarize what happened). This is a great activity to start students thinking about sound energy; however, it is not a true inquiry. Teacher demonstrations are quite time-friendly. They typically require few materials or equipment, but they engage students the least compared to other activities. Unfortunately, the cost-benefit to student learning is minimal. With a teacher demonstration, it is the teacher who does the bulk of the learning.

Structured Inquiry

Other common inquiry activities have students work in pairs or small groups to conduct an investigation. However, the outcome is predetermined, and the teacher usually sets up the investigation by providing the background information and the material resources for students to complete the predetermined steps. These are referred to as *structured inquiries*. For example, the teacher may pose the question, "Which loses its heat energy more quickly, a bathtub or a tea cup?" Each group of students may receive materials to conduct an experiment to answer this question, collect data, collaborate as a class to compile and compare data, and reach a conclusion. In this situation, the students are engaged in the work, but the teacher has guided them to complete a set of pre-determined steps. This activity started with a testable question. Students gathered data, analyzed it, and used it to formulate a conclusion. Many of the scientific practices were addressed with this investigation; however, the students could have just as easily rationalized the answer based on previous experiences. The experiment, such as it is, may really just confirm what students already know.

Guided Inquiry

One step beyond structured inquiry is *guided inquiry*. With this level of inquiry, the teacher typically poses a testable question to students. The next step, then, is for students to work to devise their own plan to reach a conclusion. Students take control of their own investigation, setting up the procedures, identifying needed materials, collecting and analyzing data, and ultimately reaching a conclusion. The teacher is there to support and guide students as they navigate their way through the inquiry process. But the inquiry is mostly student-generated. An example of guided inquiry would be to ask students, "How does the amount of sunlight affect plant growth?" or "How does the ground's surface affect bike speed?"

Open Inquiry

To truly be an *open inquiry*, students must start with a scientific question that they have generated, one that allows for research through an investigation, data analysis, and critical thinking. These are the kinds of investigations teachers hope to see during a science fair. With these investigations, students don't know the outcome. They make predictions based on research and prior knowledge. They design, conduct, and complete an investigation completely on their own. The teacher is there to guide their thinking and make sure they are on track to finish. All of the learning, from the initial inquiry to the final conclusion, is completely orchestrated and driven by the students. This is what true inquiry is all about. Possible questions may include, *Which home material makes the best sound insulator? What effects do power lines have on plant growth?* or *Do basketball shoes really help a person jump higher?* These are ideas students may be interested in, questions they may ask themselves, or an experiment they may design to find out something to which they don't know the answer.

Non-Inquiry Activities

Some "experiments" are anything but! Any activity that makes something or illustrates a concept is nothing more than a scientific model, or a *non-inquiry activity*. This includes having students create a model of a solar system, making a kaleidoscope, or cutting and gluing materials to a sheet of paper to show the parts of a flower. These are great activities. They are usually student-focused, and students enjoy doing them; however, they do not engage students in any of the eight scientific practices. There is little to no critical thinking involved. These types of activities do have a place in today's science classrooms, especially at the early primary grades but at a minimal level.

Planning for Inquiry

As illustrated, not all inquiry activities are the same. Some are more student-focused while others are more teacher-directed. In addition to the amount of student engagement versus teacher direction, inquiry activities may also vary in degrees of complexity. The more open-ended an investigation is, the more complex it becomes for students. However, open-ended investigations are the most rewarding for students, and they maximize the learning potential. Of course, teachers also must consider the time factor when designing and planning inquiry-based activities. Open-ended activities take the longest to complete, and teachers may feel as if they take up too much instructional time. Teachers need to consider all these factors, and have students participate in the most engaging activities that time and materials allow to maximize student learning.

Science by nature has a lot of inquiry. By recognizing the difference in the levels of inquiry, teachers may better plan activities to support student application of the eight mathematical practices from the Common Core Standards for Mathematics, and eventually lead them to be true inquirers. Figure 4.1 organizes the ideas described previously into the four levels of inquiry. This information is based on a summary by Heather Banchi and Randy Bell.

Figure 4.1 Levels of Scientific Inquiry

Level of Inquiry	Description and Example	Level of Teacher Direction	Level of Student Engagement
1 Confirmation	A scientific principle is confirmed. The results are known in advance. **Example:** Students model Earth's rotation and revolution.	High	Low
2 Structured Inquiry	The teacher presents a question which the students investigate following a set procedure. **Example:** Students drop various objects from the same height to see how gravity affects their fall.	Moderate	Moderate
3 Guided Inquiry	The teacher presents a question which the students investigate following a procedure they design and construct. **Example:** What factors (weight, length, or height of drop) affect the period of a pendulum?	Moderately Low	Moderately High
4 Open Inquiry	The students formulate a question and design procedures to collect data or evidence from which they may reach a reasonable conclusion. **Example:** Students design an experiment to test how different types of light (sun, incandescent, fluorescent) affect plant growth.	Low	High

(Adapted from Banchi and Bell 2008)

Science teachers in today's classrooms should quickly identify activities. These are more teacher-centered in nature. They typically don't require students to think a whole lot, or they are an end in themselves. True inquiries that ask testable questions, require data collection, analysis, and require creative thinking, lead to further investigations, are less teacher-centered, and insist that students put the eight science and engineering practices to good use. Students in today's science classrooms should be spending their time learning both science content and scientific processes.

Many activities available to science teachers may provide meaningful hands-on experiences for students, but they are not actually inquiry-based. Devising testable questions related to general science topics can be challenging. Figure 4.2 lists sample inquiry-based questions that students might investigate as part of the process of "doing" science. These can serve as models for teachers to follow when conducting inquiry activities in their classrooms.

Figure 4.2 Sample Testable Scientific Inquiries

Grade Range	Topic	Question
K–2	Earth, Sun and Moon	How does the temperature compare between day and night?
K–2	Plants	Which soil is best for growing sunflower seeds?
3–5	Rust	Which type of nails resist rust best?
3–5	Friction	Which surface creates the most friction with the bottom of my shoe?
6–8	Weather	How is humidity related to temperature?
6–8	Genetics	What is the relationship between the size of an animal and the size of its genome?
9–12	Ecology	How does the acidity of water affect the survival rate of brine shrimp?
9–12	Nutrition	How does the density of fruit affect its nutritional value?

The Scientific Method

The scientific method is a process by which students conduct a full experiment in their efforts to understand and explain something in the natural world. The scientific method is very closely related to inquiry. True inquiry and the scientific method both begin with a testable question. Additionally, they both require that students conduct a test, during which they collect data. They also both require an analysis of the data from which to form a conclusion. Teachers and students follow an organized set of procedures or steps to conduct an inquiry. We call these steps the scientific method. Publishers and reliable science resources vary in how they organize these steps. Sometimes they list six, seven, or eight steps. Although the procedures may vary slightly from author to author, the essence of the steps remains fairly consistent. Possible steps of the scientific method include:

1. Ask a testable question.
2. Conduct research about the topic.
3. Formulate a hypothesis or prediction about what will happen. Base this on prior experiences and the research.
4. Develop a procedure to follow and conduct the experiment. This includes a set of steps to follow, and materials and equipment needed.
5. Gather, organize, and analyze the data. Form a conclusion based on the evidence.
6. Communicate the results and identify other questions that arise from the test.

Example of a Structured Inquiry-Based Activity that Follows the Scientific Method

Question: What ratio of ingredients combine to make the best putty?

Research: Students conduct research on how putty is made and find various "recipes" to try.

Hypothesis: After researching this topic, students make an educated guess.

Materials:

- sealable plastic bag
- liquid white glue
- sodium borate
- water
- beakers
- stirs
- glass jars with lids
- protective gloves and eyewear
- permanent marker

Procedure:

1. Mix a 50/50 solution of glue and water. Use 200 mL of each. Place them in a glass jar. Close the lid and shake it until the water is completely gone. Use the marker. Label this jar as 50 percent solution.

2. Mix 10 mL sodium borate with 200 mL warm water in a second jar. Close the lid. Shake the jar until no particles of sodium borate remain. Use the marker. Label this jar 5 percent solution.

3. Mix these two solutions together in different ratios each in its own zipper bag to make putty.

4. Record the data.

5. Observe the properties of each putty. Decide on the one that has the best overall firmness, stickiness, and moisture.

Data Collection:

50% Glue Solution	**5% Sodium Borate Solution**	**Observations**	**Physical Properties** (color, texture, moisture content, stiffness)
15 mL	45 mL		
30 mL	30 mL		
45 mL	15 mL		
75 mL	15 mL		

Data Analysis: Students analyze their data, explaining what happened in each trial.

Conclusion: Students reach a conclusion based on the evidence they collected.

Further Questions: Students write additional testable questions that arose from conducting this experiment.

The "Nature of Science" Concepts

The skills, concepts, ideas, and practices related to following the scientific method are generally referred to as "nature of science" concepts. Appendix H of The Next Generation Science Standards (2013c) lists four nature of science understandings related to scientific practices.

- Scientific investigations use a variety of methods.
- Scientific knowledge is based on empirical evidence.
- Scientific knowledge is open to revision in light of new evidence.
- Scientific models, laws, mechanisms, and theories explain natural phenomena.

Teachers should consider the first bullet carefully. Although the scientific method is a common means of conducting an investigation, it is not the only method students might follow. Some questions may only be answered using research. For example, students could observe that they see a particular species of bird only during certain times of the year. Perhaps they see a particular species all year long, but only rarely. Students might ask, "What kind of bird is that, and why do I only see it in [spring, summer, fall, winter]?" Or, "Why do I see a bald eagle around my house? Is this bird within its range? If so, why aren't there more of them? If not, what brings it here?" Are these questions testable? Some might argue that yes, they are. Others might argue that no, they aren't. Are they inquiry-based? Students can use available resources to conduct research. They might also keep journals or logs of sightings: dates, times, locations. This data then becomes part of their evidence upon which they can draw a reasonable conclusion.

Recommended URLs

Chapter 2

AIMS Education Foundation
http://www.aimsedu.org/

Arcadia National Park
http://www.nps.gov/acad/index.htm

College of the Atlantic
http://www.coa.edu/index.htm

Edmodo
https://www.edmodo.com/ *requires login*

Edutopia
http://www.edutopia.org/

Jason Project
http://www.jasonproject.org/

National Aeronautic and Space Administration (NASA)
http://www.nasa.gov

National Geographic for Teachers
http://education.nationalgeographic.com/education/?ar_a=1

National Oceanic and Atmospheric Association (NOAA)
http://www.oar.noaa.gov/k12

National Science Teachers Association
http://www.nsta.org/

Pinterest
https://pinterest.com/

Project WET
http://projectwet.org/

Sample Summative Writing Project

News Alert: Ecosystem!

Situation: You are a reporter for a local area news channel. Your manager has asked you and a team of reporters to do a special story on an ecosystem that is being threatened by an invasive species.

Task: Write a news report about a real or fictional ecosystem. Explain how an invasive species is threatening this ecosystem.

Required: Your ecosystem news report must:

- Have a clear beginning, middle, and end
- Mention an invasive organism (plant or animal), or pollution
- Include a description as to how the invasive organism or pollution negatively affects the ecosystem
- Name native plants and animals and identify them as producers, consumers, or decomposers; and herbivores, carnivores, or omnivores
- Include an energy source

Directions

Prewriting

1. Decide on an ecosystem. It may be real or fictional.
2. List the organisms (plants and animals) you will include in your ecosystem. Identify the invasive organism. Identify the energy source.
3. Plan your news report.

Drafting

4. Write your news report. Include mention of all the necessary parts of the ecosystem (see above).
5. Develop the story. This news report is really about the invasive organism.
6. Wrap up your story. What will scientists do next, or what is their plan to save the ecosystem?

Revise and Edit

7. Be sure your story has a clear beginning, middle, and end.
8. Revise some verbs to show more specific action.

Publish your story.

9. Read your news report. Everyone in the group should have a part.

Sample Summative Writing Project Evaluation

Directions: Review these criteria. This is how your ecosystem news report will be graded. Review your news report. Be sure it has all the makings of an exciting news story!

Criteria	Possible	Earned
1. The project demonstrated a thorough understanding of an ecosystem.	10	________
2. The project was neat, well organized, and an example of the student's best work.	20	________
3. The ecosystem included an invasive organism (plant OR animal) OR pollution.	10	________
4. It was apparent OR explained how the invasive organism/pollution negatively affected the ecosystem.	10	________
5. The ecosystem contained native plants.	10	________
6. The ecosystem contained native animals.	10	________
7. The ecosystem contained a producer, consumer, and decomposer (5 pts each).	15	________
8. The energy source for the ecosystem was apparent or explained when presented.	5	________
9. Students clearly identified the animals in their ecosystem as carnivores, herbivores, or omnivores.	10	________
TOTAL:	100	________

Teacher Comments:

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