WHY DOES INQUIRY MATTER?

BECAUSE THAT'S WHAT SCIENCE IS ALL ABOUT!

BSCS

Celebrating 50 Years
1958 - 2008

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5415 Mark Dabling Blvd.
Colorado Springs, CO 80918
www.bscs.org

KENDALL/HUNT PUBLISHING COMPANY
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GETTING STARTED

For more than 30 years, the literature in science education has documented increased achievement and improved retention of science concepts when students are taught using curriculum materials that have an inquiry approach. Of this work, most has focused on biology, and frequently on BSCS curriculum materials. If you review this literature, you will notice quickly that many research studies were conducted in the mid-1960s and early 1970s, but there are a few recent studies that reinforce these earlier findings.

One of the greatest challenges is trying to understand what inquiry is. This is because inquiry is one simple word used to describe a complex set of abilities and ideas about science. Consider the 14 statements about inquiry on pages 2 and 3. Which ones mean inquiry to you? What challenges are there if you try to consider all these ideas as inquiry? What are the implications for your students' learning experiences? For your teaching? For the instructional materials you use?

Statements about science as inquiry

1. “Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations on the evidence derived from their work.” (NRC, 2000, p. 1)

2. “Inquiry refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world.” (NRC, 2000, p. 1)

3. “Inquiry investigations in the classroom can be highly structured by the teacher so that students proceed toward known outcomes, or inquiry investigations can be free-ranging explorations of unexplained phenomena. Both have their place in science classrooms.” (NRC, 2000, pp. 10–11)

4. “One critical aspect of science education is to help children develop the skills they need to think like scientists in their pursuit of understanding.” (National Science Foundation [NSF], 1999, p. 1)

5. “All hands-on is not inquiry; all inquiry is not hands-on.” (NSF, 1999, p. 34)

6. “Inquiry teaching is not chaotic—it is a carefully choreographed activity.” (NSF, 1999, p.36)

7. “In order for inquiry to be effective, a teacher must lay a foundation in which students can begin to take more responsibility for their own learning.” (NSF, 1999, p. 36)

Statements about science as inquiry

8. “Good science inquiry involves learning through direct interaction with materials and phenomena.” (NSF, 1999, p. 43)

9. “Inquiry science requires student discussion with others—working cooperatively and sharing ideas. In addition to these being important skills to learn, dialogue and socially gathered and shared information is a powerful means toward building individual conceptual understanding.” (NSF, 1999, p. 48)

10. “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.” (NSF, 1999, p. 61)

11. “In the inquiry classroom, the teacher’s role becomes less involved with direct teaching and more involved with modeling, guiding, facilitating, and continually assessing student work. Teachers in inquiry classrooms must constantly adjust levels of instruction to the information gathered by that assessment.” (NSF, 1999, p. 82)

12. ”To use inquiry to answer a question, you have to become good at knowing what you don’t know. I would argue that that’s exactly the opposite of what happens in schools. Classrooms focus on what you do know (or are supposed to know) and leave you unprepared to deal with the things you don’t know.” (NSF, 1999, p. 109)

13. “Inquiry is a content different from other content. It’s not something to be studied for a short time and then left behind. Inquiry has a meta-content character that demands its presence while all the other content is being learned.” (Wheeler, 2000, p. 18)

14. “To implement inquiry in the classroom, we see three crucial ingredients: (1) teachers must understand precisely what scientific inquiry is; (2) they must have sufficient understanding of the structure of the discipline itself; and (3) they must become skilled inquiry teaching techniques.” (Bybee, 2000, p. 30)

The Abilities and Understandings of Inquiry

The text in the *National Science Education Standards* (National Research Council [NRC], 1996; hereafter referred to as the *NSES*) challenges us to consider three perspectives of inquiry: the teaching strategies that support student inquiry, the abilities of inquiry, and the understandings of inquiry. This is a far cry from the simplistic "processes of science" that characterized these discussions years ago. In fact, the authors of the standards indicate that the abilities and understandings of inquiry are actually essential components of the *science content* in the K–12 science curriculum. Many state standards support this position also, although not always as explicitly as the national standards.

Read and consider the following excerpts from the *NSES* content standards that describe what all students should be able to do and understand with respect to scientific inquiry upon finishing fourth grade, eighth grade, and their K–12 science education.

The items in table 1 are the skills all students should develop by fourth grade, eighth grade, and finally, graduation. Do *all* the graduates in your local school district adequately meet these standards? What are the consequences if they don't?

Table 2 includes the key ideas about scientists' work that every fourth and eighth grader should have and every high school graduate should understand. Do your students have this grounding as they move to fifth grade, middle school, and high school? What would need to change so that all students could think and do science at this level? What would be the positive and long-lasting consequences of an elementary science education that ensured that students understood and could conduct scientific inquiry? Do the graduates in your local community really understand these ideas? Do writers for your local paper indicate an understanding of these features of science when reporting on new research findings? What kind of difference would it make if *all* graduates were competent in these abilities and understandings? Would it change the way citizens vote on science-related social issues? Would it help citizens become more knowledgeable about and more responsible for their own health and health care? Would it encourage citizens to safeguard the environment?

At one time, science educators engaged in a "process versus content" debate, thinking that spending time teaching the processes of science meant trading off time teaching the "real" content of science. We are no longer in this debate. Inquiry *is* content. What we have called content in the past to a large extent is really the context and results of inquiry. If science is a way to ask questions about and develop explanations for phenomena in the natural world, there is no science without inquiry.

So how do we elevate inquiry to its rightful status in the science curriculum? First, we need to learn to recognize inquiry in our classrooms. Second, we need to choose instructional materials that promote the teaching and learning of inquiry. Third, we need to implement ongoing professional development programs that help teachers enact a vision of the inquiry-based classroom, support the implementation of new instructional materials, and coordinate assessment priorities with an emphasis on inquiry.

Table 1
Abilities of scientific inquiry at fourth, eighth, and 12th grades
All students should have developed the following abilities of scientific inquiry
by the end of fourth grade: ■ Ask a question about objects, organisms, and events in the environment. ■ Plan and conduct a simple investigation. ■ Employ simple equipment and tools to gather data and extend the senses. ■ Use data to construct a reasonable explanation. ■ Communicate investigations and explanations.
by the end of eighth grade: ■ Identify questions that can be answered through scientific investigations. ■ Design and conduct a scientific investigation. ■ Use appropriate tools and techniques to gather, analyze, and interpret data. ■ Develop descriptions, explanations, predictions, and models using evidence. ■ Think critically and logically to make the relationships between evidence and explanations. ■ Recognize and analyze alternative explanations and predictions. ■ Communicate scientific procedures and explanations. ■ Use mathematics in all aspects of scientific inquiry.

Table 1 ***(continued)***

by the end of high school:

- Identify questions and concepts that guide scientific investigations.
- Design and conduct scientific investigations.
- Use technology and mathematics to improve investigations and communications.
- Formulate and revise explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Communicate and defend a scientific argument.

Table 2

Understandings of scientific inquiry at fourth, eighth, and 12th grades

By the end of the stated grade, all students should understand that the work scientists do includes the following:

Fourth grade

- Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world.
- Scientists use different kinds of investigations depending on the questions they are trying to answer.
- Simple instruments, such as magnifiers, thermometers, and rulers, provide more information than scientists obtain using only their senses.
- Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge).
- Scientists make the results of their investigations public; they describe the investigations in ways that enable others to repeat the investigations.
- Scientists review and ask questions about the results of other scientists' work.

Eighth grade

- Different kinds of questions suggest different kinds of scientific investigations.
- Current scientific knowledge and understanding guide scientific investigations.

Table 2 *(continued)*

- Mathematics is important in all aspects of scientific inquiry.
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
- Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.
- Science advances through legitimate skepticism.
- Scientific investigations sometimes result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data.

End of high school

- Scientists usually inquire about how physical, living, or designed systems function.
- Scientists conduct investigations for a wide variety of reasons.
- Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science.
- Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.
- Scientific explanations must adhere to criteria such as: a proposed explanation must be logically consistent; it must abide by the rules of evidence; it must be open to questions and possible modification; and it must be based on historical and current scientific knowledge.

(continued)

- Results of scientific inquiry—new knowledge and methods—emerge from different types of investigations and public communication among scientists. In communicating and defending the results of scientific inquiry, arguments must be logical and demonstrate connections between natural phenomena, investigations, and the historical body of scientific knowledge. In addition, the methods and procedures that scientists used to obtain evidence must be clearly reported to enhance opportunities for further investigation.

INQUIRY IN THE CLASSROOM

Rather than write about how to recognize inquiry in the classroom, we have created an activity to demonstrate it. The classroom case studies that follow provide examples from the elementary through high school grades.

Process and Procedure

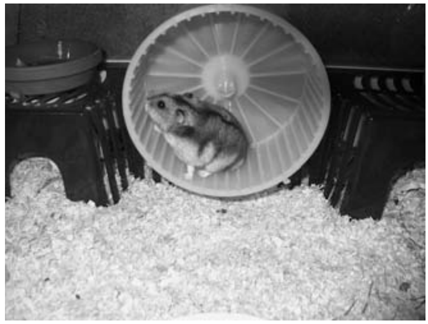
1. Turn to the case studies on pages 12–14 and read the six scenarios.
2. Review the summary of observations in table 3 (found on page 15) and answer the questions.

Classroom Case Studies

Teaching Science as Inquiry

A teacher wanted to see inquiry in action, so she visited six different classrooms. Her considerations included the content of lessons, the teaching strategies, the student activities, and the outcomes—what students learned. During five days in each classroom, she made the following observations.

Classroom #1



The students engaged in an investigation initiated by significant student interest. A student asked what happened to the water in a watering can. The can was almost full on Friday and almost empty on Monday. One student proposed that Willie the pet hamster left his cage at night and drank the water. The teacher encouraged the students to find a way to test this idea. The students devised a test in which they covered the water so Willie could not drink it. Over several days, they observed that the water level did not drop. The teacher then challenged the students to think about other explanations. The students' questions resulted in a series of full investigations about the disappearance of water from the container. The teacher emphasized strategies such as asking students to consider alternative explanations, using evidence to form their explanations, and designing simple investigations to test an explanation. The science teacher never did explain evaporation and related concepts.

Classroom #2

Students investigated batteries and bulbs to learn about electricity. The teacher gave teams of students a battery, a bulb, and a piece of wire. To begin, the teacher told the students to use the materials and to "light the bulb." In time, the student teams lit the bulb and made observations about the arrangement of the battery, the wire, and the bulb.

The teacher then provided other batteries, wires, small buzzers, and other materials and asked the students to explore different arrangements and see what they could learn. As the students continued their activity, the teacher pointed out certain results of their battery, bulb, wire, and buzzer systems. After several days of exploration with the materials, the teacher introduced the ideas that (1) electricity in circuits can produce light, heat, sound, and magnetic effects; (2) electrical circuits require a complete loop through which an electrical current can pass; and (3) electrical circuits provide a means of transferring electrical energy when heat, light, and sound are produced. In the end, students learned some basic ideas about electricity.

Classroom #3

In this classroom, the students selected from among several short stories that provided discussions of scientists and their work. Stories included Louis Pasteur, Marie Curie, Jonas Salk, and Barbara McClintock. Over a three-week period, every student read one of the stories as homework. Then, in groups of three, all student groups discussed and answered the same questions: "What questions did the scientist ask?" "What type of investigations did the scientist conduct?" "What instruments and equipment did the scientist use?" "How did the scientist use observations to answer his or her questions?" After reading the stories and completing the discussion questions, the teacher had the groups prepare oral reports on the topic "how scientists do their investigations."

Classroom #4

The students were engaged in an investigation initiated by significant student interest. A student asked why the plants on the windowsill all seemed to be facing the window. The plants had been pointing toward the classroom on Friday, and by Monday, all the leaves and flowers were facing away from the classroom. One student proposed that the teacher had turned all the plants around on Monday morning. The teacher indicated that this had not been done and encouraged the students to ask other questions that they could test. Eventually, the students decided to find out if the plants could follow the light. The students devised a test in which they covered half the plants for several days and turned the other half back toward the classroom. Over several days, they observed that the uncovered plants turned back to the window, but the covered plants did not. The teacher then challenged the students to think about other explanations. The students' questions resulted in a series of full investigations about plant phototropism. The teacher emphasized strategies such as asking students to consider alternative explanations, using evidence to form their explanations, and designing simple investigations to test an explanation. The science teacher never did explain phototropism and related concepts.

Classroom #5

Students investigated fossils to learn about biological evolution. The teacher distributed two similar, but slightly different, molds with dozens of fossil brachiopods. The students measured the lengths and widths of the two populations of brachiopods. The teacher asked if the differences in length and width might represent evolutionary change. As the students responded, the teacher asked, "How do you know?" "How could you support your answer?" "What evidence would you need?" "What if the fossils were in the same rock formation?" "Are the variations in length and width just normal variations in the species?" "How would a difference in length or width help a brachiopod adapt better?" The fossil activity provided the context for students to learn about the relationships among (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) the finite supply of resources required for life, and (4) the ensuing selection by the environment for those offspring better able to survive and leave offspring. In the end, students learned about changes in the variations of characteristics in a population—biological evolution.

Classroom #6

In this science classroom, students selected from among several books that provided extended discussions of scientific work. Readings included *The Double Helix, The Beak of the Finch,* and *A Feeling for the Organism.* Over a three-week period, each student read one of the books as homework. Then, in groups, the students discussed and answered the same questions: "What led the scientist to the investigation?" "What conceptual ideas and knowledge guided the inquiry?" "What reasons did the scientist cite for conducting the investigations?" "How did technology enhance the gathering and manipulation of data?" "What role did mathematics play in the inquiry?" "Was the scientific explanation logically consistent? Based in evidence? Open to skeptical review? Built on a knowledge base of other experiments?" After reading the books and completing the discussion questions, the teacher had the groups prepare oral reports on the topic "the role of inquiry in science."

Table 3

Summary of observations

	Classroom #1	Classroom #2	Classroom #3	Classroom #4	Classroom #5	Classroom #6
Content of lessons	Changing water level in an open container	Investigation of electricity	Stories of scientists and their work	Movement of plants	Investigation of variations in fossils	Stories of scientists and their work
Teaching strategies	Challenge students to think about proposed explanations and use evidence to support conclusions	Provide batteries, bulbs, and wires and ask students to light the bulbs and explore different arrangements of materials	Provide questions to focus discussions of readings	Challenge students to think about proposed explanations and use evidence to support conclusions	Provide molds of fossils and ask questions about student measurements and observations	Provide questions to focus discussions of readings
Student activities	Design simple, but full, investigations	Get bulbs to light, buzzers to make sounds	Read and discuss stories about scientific investigations	Design simple, but full, investigations	Measure fossils and use data to answer questions	Read and discuss a book about scientific investigations
Student outcomes	Develop the ability to reason using logic and evidence to form an explanation	Understand some of the basic concepts of electricity	Understand scientific inquiry as it is demonstrated in the work of scientists	Develop the ability to reason using logic and evidence to form an explanation	Understand some of the basic concepts of biological evolution	Understand scientific inquiry as it is demonstrated in the work of scientists

Stop and Think

Steps 1 and 2 should have engaged your thinking about teaching science as inquiry. To further clarify your thinking, take a few minutes and respond to the following questions. Refer to the case studies or summary table as often as necessary. Select the best answers and provide brief explanations for your answers.

1. Which classroom scene would you cite as the best example of teaching science as inquiry?
   A. 1
   B. 2
   C. 3
   D. 4
   E. 5
   F. 6
   G. None of the classrooms
   H. All of the classrooms
2. If teaching science as inquiry is primarily interpreted to mean using laboratory experiences to learn science concepts, which classrooms were the best example?
   A. 1
   B. 2
   C. 3
   D. 4
   E. 5
   F. 6
   G. None of the classrooms
   H. All of the classrooms
3. Suppose students had numerous experiences with the same teaching strategies and student-originated activities as classrooms #1 and #4, but the questions the students pursued varied. What would you predict as the general learning outcomes for students?
   A. Their thinking abilities, understanding of subject matter, and understanding of inquiry would be *higher* than students who were in the other two classes.
   B. Their thinking abilities, understanding of subject matter, and understanding of inquiry would be *lower* than students who were in the other two classes.
   C. Their thinking abilities would be higher, and understanding of subject matter and inquiry would be *lower* than students who were in the other two classes.

D. Their understanding of subject matter would be *higher,* and thinking abilities and understanding of inquiry would be *lower* than students in the other two classes.
E. All learning outcomes would be the same as that of the students in the other two classes.

4. Suppose the teacher continues observing the classrooms for another week. What would you recommend she look for in order to formulate an answer to the question, "What is teaching science as inquiry?"
   A. What the students learned about scientific inquiry
   B. What teaching strategies the teacher used
   C. What science information, concepts, and principles the students learned
   D. What inquiry abilities the students developed
   E. What teachers should know and do to achieve the different learning goals of scientific inquiry
5. Based on the observations of these classrooms, which of the following generalizations about teaching science as inquiry would you make?
   A. Overuse of one teaching strategy may constrain opportunities to learn some science subject matter.
   B. There may be benefits and trade-offs of different teaching strategies and student activities.
   C. The potential learning outcomes for any one sequence of lessons may be greater than the sum of the individual lessons.
   D. Different learning outcomes may require different teaching strategies.
   E. All of the above
6. Based on these observations, the science teacher proposes that teaching science as inquiry may have multiple meanings. Which of the following would you recommend as a next step in her investigation?
   A. Explore how others have answered the question, "What is teaching science as inquiry?"
   B. See how the *National Science Education Standards* explain science as inquiry.
   C. Elaborate on the implications of teaching science as inquiry in the context of classrooms.
   D. Try teaching science as inquiry in order to evaluate the approach in school science programs.
   E. All of the above

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3. Read the essay "Constructing a New View of Inquiry."

Reading

Constructing a New View of Inquiry: A Personal Reflection by Rodger W. Bybee

My use of the initial observations of classrooms and questions set the context for this essay. The questions based on those observations allowed you to think deeply about the observations and explore several issues associated with the theme of teaching science as inquiry. Returning to the observations and questions now provides an opportunity to separate inquiry as content and inquiry teaching strategies and establish a perspective on teaching science as inquiry.

Question 1 probes the dominant perception of teaching science as inquiry. If your view was that inquiry is primarily activity directed by students, you probably answered A or D. If it was using laboratory experiences to teach the subject, you probably answered B or E. Few teachers answer C or F, for most do not view understanding scientific inquiry as a primary aim of school science. Those who responded H probably explained that some elements of all six classrooms contained inquiry.

Question 2 emphasizes the conception that most secondary teachers hold of inquiry: inquiry as technique or laboratory experiences for learning science concepts. The best answer is B or E. In classrooms #1 and #4, students had many opportunities to develop the abilities of inquiry; and students in classrooms #3 and #6 developed an understanding of scientific inquiry. But none of those four classes concentrated on the subjects of science: concepts of life, Earth, and physical phenomena.

Question 3 was designed to probe the idea of inquiry as a teaching strategy and engage your thinking about this as a singular approach to teaching science and the implied learning outcomes for students. If you used this approach all the time, what would students learn and what would they not learn? I suggest that the best answer is C. The primary assumption here is that classroom experiences of inquiry alone do not guarantee the understanding of subjects. Teachers should make explicit connections between the experiences and the content of inquiry and subject.

Question 4 asks for a generalization about the connection between teaching strategies and learning outcomes. I suggest that the best answer is E because each of the others has some basis in practical truth.

In question 5, the teacher could look at any of the responses or could look at all. Response E best anticipates a theme of this essay: that science teachers must have some understanding of scientific inquiry and a variety of teaching strategies and abilities to help students learn science subjects and the content of inquiry.

Question 6 organizes the reader's thinking to a breadth of thinking about inquiry. The evaluation of my success and yours lies in E and especially D.

Source: Adapted from Bybee, R. W. (2000). Teaching science as inquiry. In J. Minstrell, & E. H. Van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 37–38). Washington, DC: American Association for the Advancement of Science.

4. Consider your responses in comparison to the author's view in "Constructing a New View of Inquiry." If possible, do this by having a discussion with your colleagues.

THE ESSENTIAL FEATURES OF INQUIRY*

To begin shifting toward a more-inquiry oriented classroom, it helps to consider five essential features identified in *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (NRC, 2000):

1. Learner engages in scientifically oriented questions.
2. Learner gives priority to evidence in responding to questions.
3. Learner formulates explanations from evidence.
4. Learner connects explanations to scientific knowledge.
5. Learner communicates and justifies explanations.

*This section adapted with permission from *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* © 2000 by the National Academy of Sciences. Courtesy of the National Academies Press, Washington, D.C.

Essential Feature 1: Learners Are Engaged by Scientifically Oriented Questions

Scientifically oriented questions center on objects, organisms, and events in the natural world; they connect to the science concepts described in the content standards. They are questions that lend themselves to empirical investigation and lead to gathering and using data to develop explanations for scientific phenomena. Scientists recognize two primary kinds of scientific questions. Existence questions probe origins and include many "why" questions. Why do objects fall toward Earth? Why do some rocks contain crystals? Why do humans have chambered hearts? Many why questions cannot be addressed by science. There are also causal and functional questions, which probe mechanisms and include most of the "how" questions. How does sunlight help plants grow? How are crystals formed?

Students often ask why questions. In the context of school science, many of these questions can be changed into how questions and thus lend themselves to scientific inquiry. Such change narrows and sharpens the inquiry and contributes to its being scientific.

In the classroom, a question robust and fruitful enough to drive an inquiry generates a need to know in students, stimulating additional questions of how and why a phenomenon occurs. The initial question may originate from the learner, the teacher, the instructional materials, the World Wide Web, some other source, or some combination. The teacher plays a critical role in guiding the identification of questions, particularly when they come from students. Fruitful inquiries evolve from questions that are meaningful and relevant to students, but they also must be able to be answered by students' observations and the scientific knowledge they obtain from reliable sources. The knowledge and procedures students use to answer the questions must be accessible and manageable, as well as appropriate to the students' developmental level. Skillful teachers help students focus their questions so that they can experience both interesting and productive investigations.

Essential Feature 2: Learners Give Priority to Evidence, Which Allows Them to Develop and Evaluate Explanations That Address Scientifically Oriented Questions

As the *NSES* notes, science distinguishes itself from other ways of knowing through the use of empirical evidence as the basis for explanations about how the natural world works. Scientists concentrate on getting accurate data from observations of phenomena. They obtain evidence from observations and measurements taken in natural settings such as oceans, or in contrived settings such as laboratories. They use their senses; instruments, such as telescopes, to enhance their senses; and instruments that measure characteristics that humans cannot sense, such as magnetic fields. In some instances, scientists can control conditions to obtain their evidence; in other instances, they cannot control the conditions or control would distort the phenomena, so they gather data over a wide range of naturally occurring conditions and over a long enough period of time so that they can infer what the influence of different factors might be. The accuracy of the evidence gathered is verified by checking measurements, repeating the observations, or gathering different kinds of data related to the same phenomena. The evidence is subject to questioning and further investigation.

The above paragraph explains what counts as evidence in science. In their classroom inquiries, students use evidence to develop explanations for scientific phenomena. They observe plants, animals, and rocks and carefully describe their characteristics. They take measurements of temperature, distances, and time and carefully record them. They observe chemical reactions and moon phases and chart their progress. Or they obtain evidence from their teacher, instructional materials, the

World Wide Web, or elsewhere to “fuel” their inquiries. As the *NSES* (NRC, 1996) notes, “explanations of how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific.”

Essential Feature 3: Learners Formulate Explanations from Evidence to Address Scientifically Oriented Questions

Although similar to the previous feature, this aspect of inquiry emphasizes the path from evidence to explanation, rather than the criteria for and characteristics of the evidence. Scientific explanations are based on reason. They provide causes for effects and establish relationships based on evidence and logical argument. They must be consistent with experimental and observational evidence about nature. They respect rules of evidence, are open to criticism, and require the use of various cognitive processes generally associated with science—for example, classification, analysis, inference, and prediction—and general processes such as critical reasoning and logic.

Explanations are ways to learn about what is unfamiliar by relating what is observed to what is already known. So explanations go beyond current knowledge and propose some new understanding. For science, this means building upon the existing knowledge base. For students, this means building new ideas upon their current understandings. In both cases, the result is proposed new knowledge. For example, students may use observational and other evidence to propose an explanation for the phases of the moon, for why plants die under certain conditions and thrive in others, and for the relationship of diet to health.

Essential Feature 4: Learners Evaluate Their Explanations in Light of Alternative Explanations, Particularly Those Reflecting Scientific Understanding

Evaluation, and possible elimination or revision of explanations, is one feature that distinguishes scientific inquiry from other forms of inquiry and subsequent explanations. One can ask questions such as, "Does the evidence support the proposed explanation?" "Does the explanation adequately answer the questions?" "Are there any apparent biases or flaws in the reasoning connecting evidence and explanation?" "Can other reasonable explanations be derived from the evidence?"

Alternative explanations may be reviewed as students engage in dialogues, compare results, or check their results with those proposed by the teacher or instructional materials. An essential component of this characteristic is ensuring that students make the connection between their results and scientific knowledge appropriate in their level of development. That is, student explanations should ultimately be consistent with currently accepted scientific knowledge.

Essential Feature 5: Learners Communicate and Justify Their Proposed Explanations

Scientists communicate their explanations in such a way that their results can be reproduced. This requires clear articulation of the question, procedures, evidence, and proposed explanation and a review of alternative explanations. It provides for further skeptical review and the opportunity for other scientists to use the explanation in work on new questions.

Having students share their explanations provides others the opportunity to ask questions, examine evidence, identify faulty reasoning, point out statements that go beyond the evidence, and suggest alternative explanations for the same observations. Sharing explanations can bring into question or fortify the connections students have made among the evidence, existing scientific knowledge, and their proposed explanations. As a result, students can resolve contradictions and solidify an empirically based argument.

THE LOOK OF INQUIRY

Does inquiry always look the same? Hopefully not. Think about the variations of classroom inquiry along a continuum. Sometimes the amount of self-direction by learners is high, at other times the amount of direction from the teacher is high. Figure 2 lists key features of classroom inquiry down the left-hand column. The rows across indicate variations of implementation of that feature. A reasonable goal for the science classroom that is strong in inquiry is to make sure that every student has at least one opportunity every year that would fit in column D.

To choose instructional materials that support an inquiry-oriented classroom, consider changing how you look at materials. BSCS, in partnership with the K–12 Alliance at WestEd, has developed the Analyzing Instructional Materials (AIM) Process. This process provides a set of tools and strategies to examine instructional materials in depth to identify evidence of conceptual flow, content accuracy, the work students do, the work teachers do, and support for assessment. Figure 3 is one of the scoring rubrics for identifying and rating the work that students do. Note the emphasis on inquiry. How would you rate your current materials using this rubric?

Figure 2

Essential features of inquiry.

Feature	More -----------Amount of Learner Self-Direction-----------Less Less--------Amount of Direction from Teacher or Material--------More			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence and how to use evidence to formulate explanation
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication

Figure 3

AIM scoring rubric.

Criteria for examining the work students do*	5	3	1
Quality learning experiences: Engaging prior knowledge (HPL 1) Finding 1 from *How People Learn* (HPL 1) has implications for the design of instructional materials. To be responsive to research on learning, instructional materials should include structured strategies to elicit and challenge student preconceptions. These include strategies that encourage students to ■ activate (think about) their current understanding of a science concept; ■ make explicit (e.g., write down) their understanding of a science concept; and ■ connect their current understandings in science to new concepts.	The materials miss *few* opportunities to engage prior knowledge.	The materials miss *some* opportunities to engage prior knowledge.	The materials miss *most or all* opportunities to engage prior knowledge.
Quality learning experiences: Encouraging metacognition (HPL 3) Finding 3 from *How People Learn* (HPL 3) has implications for the design of instructional materials. To be responsive to research on learning, instructional materials should incorporate strategies that help students ■ recognize the goals of the chapter or unit as well as their own learning goals; ■ assess their own learning; and ■ reflect, over time, on *what* and *how* they have learned.	The materials miss *few* opportunities to encourage metacognition.	The materials miss *some* opportunities to encourage metacognition.	The materials miss *most or all* opportunities to encourage metacognition.
Abilities necessary to do scientific inquiry The abilities of inquiry (from the *NSES*) include ■ asking and identifying questions and concepts to guide scientific investigations, ■ designing and conducting scientific investigations, ■ using appropriate technology and mathematics to enhance investigations, ■ formulating and revising explanations and models, ■ analyzing alternative explanations and models, ■ accurately and effectively communicating results and responding appropriately to critical comments, and ■ generating additional testable questions.	The materials provide *frequent* opportunities to develop the abilities of scientific inquiry.	The materials provide *a limited number of* opportunities to develop the abilities of scientific inquiry.	The materials provide *none or very few* opportunities to develop the abilities of scientific inquiry.

Figure 3 *(continued)*

AIM scoring rubric.

Understandings about scientific inquiry The work scientists do (from the *NSES*) includes ■ inquiring about how physical, living, or designed systems function; ■ conducting investigations for a variety of reasons; ■ using a variety of tools, technology, and methods to enhance their investigations; ■ using mathematical tools and models to improve all aspects of investigations; ■ proposing explanations based on evidence, logic, and historical and current scientific knowledge; and ■ communicating and collaborating with other scientists in ways that are clear, accurate, logical, and open to questioning.	The materials provide students with *many* opportunities to understand the work scientists do and to make connections to student learning.	The materials provide students with *some* opportunities to understand the work scientists do and to make connections to student learning.	The materials provide students with *few* opportunities to understand the work scientists do and to make connections to student learning.
Accessibility When addressing the diversity of learners, consider the following: ■ Varied learning abilities and disabilities ■ Special needs (e.g., auditory, visual, physical, speech, emotional) ■ English language proficiency ■ Cultural differences ■ Different learning styles ■ Gender	The work students do is *consistently accessible* to diverse learners, providing opportunities for all students to achieve.	The work students do is *often accessible* to diverse learners, providing some opportunities for all students to achieve.	The work students do is *rarely accessible* to diverse learners, providing limited opportunities for all students to achieve.

*Criteria adapted with permission from *National Science Education Standards* © 1996 and *How People Learn: Brain, Mind, Experience, and School* © 1999 by the National Academy of Sciences. Courtesy of the National Academies Press, Washington, D.C.

RESOURCES FOR LEARNING ABOUT INQUIRY

We encourage you to further explore how to implement inquiry in the classroom. We begin with resources to help you teach inquiry, then provide evidence for its value to students.

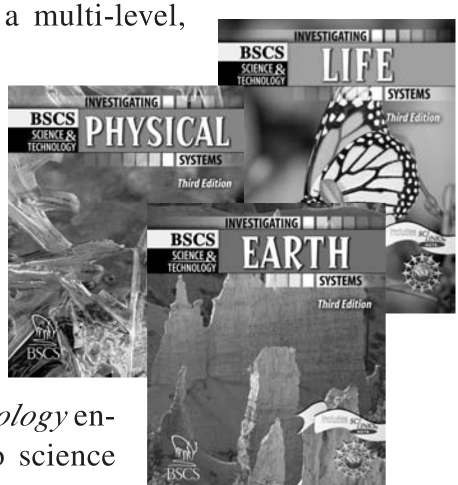
Science Curricula

BSCS Science Tracks

BSCS Science Tracks is a comprehensive, modular, kit-based elementary school science program that includes a full-year of instruction at each grade level, K–5. At each grade level, K–5, there are four modules, one each in physical science, earth and space science, life science and science and technology. Because of its hands-on, collaborative structure, the program is appropriate for students of all ability levels.

In *BSCS Science Tracks,* students learn basic science concepts and inquiry skills, as defined by the content, teaching and assessment standards from the *NSES* and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science). The curriculum presents the concepts and skills through engaging experiences that involve students in the processes of scientific inquiry and technological design. Each module clearly defines the standards that students are to meet and provides a sequence of age-appropriate, constructivist learning experiences organized according to the 5E learning cycle.

BSCS Science and Technology



BSCS Science & Technology is a multi-level, thematic program for the middle grades that integrates life, earth-space and physical sciences in the context of themes and issues that have meaning for science students. Using hands-on activities and the BSCS 5E Instructional Model in a cooperative learning environment, BSCS *Science & Technology* encourages an inquiry approach to science and aligns with the *NSES.*

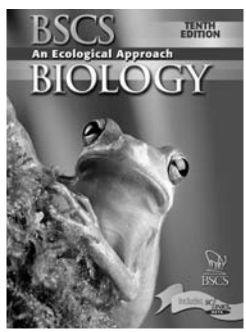
BSCS Science & Technology creates opportunities for students to learn skills, develop concepts, and acquire attitudes in many areas of science and technology. In this curriculum, students develop a conceptual understanding of the foundations of science and technology while they study specific concepts, such as the theory of plate tectonics, the particle theory of matter, the chromosome theory of inheritance, the theory of evolution, principles of design, cost-and-benefit analysis and systems analysis. Students also learn scientific and technological attitudes, such as accepting ambiguity, searching for evidence, working to support and justify answers, recognizing inferences and not always expecting right and wrong answers or simplistic solutions for complex scientific questions or for technological problems.

BSCS Biology: A Human Approach

BSCS Biology: A Human Approach is a standards-based, introductory biology program appropriate for students of all abilities. The program involves students in conceptual biology by using a human perspective, organizes content around six unifying themes and teaches through inquiry, hands-on activities and the BSCS 5E instructional model. The thematic approach encourages depth of coverage rather than breadth and, with its emphasis on a human perspective, the text presents biology in a context that will be relevant to students' lifelong learning.

BSCS Biology: An Ecological Approach (Green Version)

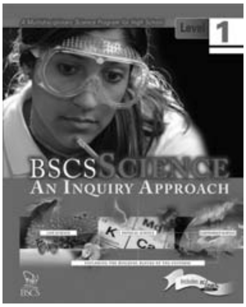
BSCS's *Green Version* textbook integrates the major concepts of biology into an ecological framework. Embedded into the curriculum are fundamental concepts such as science as inquiry, the history of science and the impact of science on society, and the diversity of life. Using a student-centered, active-learning approach, *Green Version* offers students a rich array of hands-on



activities and laboratories that develop inquiry skills and conceptual understanding. The students acquire and retain an in-depth understanding of biology when they are directly involved with the concepts and skills they are learning. *Green Version* emphasizes the process of discovery over the memorization of facts so that students don't just learn about science, they *think* science.

BSCS Science: An Inquiry Approach

BSCS Science: An Inquiry Approach is a ground-breaking, three-year multidisciplinary science program for high school. This program features a strong inquiry thread throughout the core concepts in physical science, life science, and earth-space science.



This curriculum engages students across the disciplines in relevant contexts that explore the standards related to science in a personal and social perspective, as well as science and technology. The BSCS 5E instructional model structures the learning experiences for students through each chapter.

BSCS Science: An Inquiry Approach provides high school students nationwide with a rigorous, cohesive alternative to the traditional sequence of biology, chemistry, and physics. When students complete all three years of the program, they will have been introduced to all of the national standards for grades 9-12.

ARTICLES OF INTEREST

Dispelling the myth: Is there an effect of inquiry-based science teaching on standardized reading scores? Available at http://sustainability2002.terc.edu/invoke.cfm/page/729

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5415 Mark Dabling Blvd.
Colorado Springs, CO 80918
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Fax: (719) 531-9104
www.bscs.org
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