

Chapter 1

Constructing an Understanding of Inquiry

Three Designations of Inquiry

One of the most debated about topics in science education over the last 15 years has been inquiry. Whether you are discussing science literacy, the nature of science, standards, instructional strategies, or assessment, sooner or later the word “inquiry” will likely work its way into the conversation. Thus for many teachers, constructing an understanding of inquiry becomes a primary necessity to contribute to an intellectual discussion on science education. Since the primary purpose of this book is to enable high school science teachers to not only develop an understanding of inquiry, but also to gain an appreciation of the skills, dispositions, and attitudes in creating a “classroom culture of inquiry” within themselves as well as their classrooms, we will start with three designations that are often tossed about as if they were actually all the same: inquiry, science inquiry, and scientific inquiry.

For the sake of this book, we will define and attempt to use each term differently. When referring to inquiry, we will use the term in the general, broad-spectrum of inquiring; meaning posing questions, searching for answers, probing counter-intuitive phenomena, or just simply acting inquisitively. In this wide-ranging sense, science certainly does not have the monopoly on inquiry - one can find inquiry-based teaching and learning in any subject area and at any grade level. When we refer to science inquiry, we will speak to those science activities and investigations that are characteristic of inquiry-based instruction: investigations that are predicated upon a question whether posed by the teacher, the science textbook, or the students themselves. In Chapter 7, four different levels of science inquiries are presented. In the ensuing chapters you will find numerous examples of science inquiries to illustrate ideas and understandings made throughout the book. Lastly, when we refer to scientific inquiry, we will denote those critical thinking skills, reasoning skills, and habits of mind employed during the process of doing a scientific investigation. Scientific inquiry also involves and engages the student’s knowledge, skills, and attitudes.

Inquiry and Habits of Mind

Scientific inquiry provides an excellent means to foster the development of students' habits of mind. Marzano (1992) describes habits of mind as mental habits individuals develop to render their thinking. Habits of mind often encompass higher-order thinking skills, critical and scientific reasoning skills, problem-solving skills, communication and decision-making skills, and metacognition - being aware of your own thinking. Costa and Kallick (n.d.) describe habits of mind as "having dispositions toward behaving intellectually when confronted with problems, the answers to which are not immediately known" (p. 1). Although examples of habits of mind vary from author to author, the attributes usually common in science include the following:

- Commitment
- Creativity
- Curiosity
- Diligence
- Fairness
- Flexibility
- Imagination
- Innovation
- Integrity
- Openness
- Persistence
- Reflection
- Sensitivity
- Skepticism
- Thoughtfulness
- Wonder

As we journey further into our understanding of inquiry, we will come to see how inquiry-based classrooms promote critical thinking skills and habits of mind, and empower students to become independent, life-long learners. Hester (1994) tells us that inquiry involves critical thinking processes such as methods of diagnosis, speculation, and hypothesis testing. The method of inquiry gives students the opportunity to confront problems, and generate and test ideas for themselves...The emphasis is on ways of examining and

explaining information (events, facts, situations, behaviors, etc.). Students, when taught for the purposes embodied in inquiry, are encouraged to evaluate the usefulness of their beliefs and ideas by applying them to new problem situations and inferring from them implications for future courses of action. (pp. 116-117)

The *Benchmarks for Science Literacy* (AAAS, 1993) suggest “by the end of the 12th grade, students should know why curiosity, honesty, openness, and skepticism are so highly regarded in science and how they are incorporated into the way science is carried out; exhibit those traits in their own lives and value them in others” (p. 287).

Why are habits of mind so important to inquiry? They are important to inquiry because they communicate a teacher’s values and beliefs about what constitutes good teaching and learning. In turn, habits of mind manifest our classroom behaviors and direct the “personality” of the learning environment. As students engage in scientific inquiry, they demonstrate these attributes and behaviors in a collective sense as part of completing an investigation. According to the AAAS (1990):

It is also important for people to be aware that science is based upon everyday values even as it questions our understandings of the world and ourselves. Indeed, science is in many respects the systemic application of some highly regarded human values...Scientists did not invent any of these values...but the broad field of science does incorporate and emphasize such values and drastically demonstrates just how important they are for advancing human knowledge and welfare. Therefore, if science is taught effectively, the results will be to reinforce such generally desirable human attributes and values – curiosity, openness to new ideas, and skepticism. (p. 185)

What the *National Science Education Standards* Say About Inquiry

In 1996, the National Research Council (NRC) released the *National Science Education Standards (NSES)*. In regard to the inquiry standards, the NRC states:

Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see 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)

However, according to the Standards, doing inquiry involves more than just utilizing science process skills in the classroom. The *Standards* require that high school teachers plan activities that engage students in combining process skills and critical reasoning skills to develop and appreciation for and understanding of science. According to the *Standards* (NRC, 1996), engaging high school students in inquiry helps to develop

- an understanding of scientific concepts,
- an appreciation of “how we know” what we know in science,
- an understanding of the nature of science,
- skills necessary to become independent inquirers about the natural world, and
- the dispositions to use the skills, abilities, and attitudes associated with science.

The *Standards* also highlight the ability to conduct inquiry and develop an understanding about scientific inquiry:

Students in all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about the relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. (NRC, 1996, p. 105)

The inquiry standards set forth by the NRC (1996) are divided into three separate grade levels or junctures. Each juncture identifies inquiry standards specific for that grade. These standards help science educators to define what students should know and be able to do. Reading the inquiry standards for grades 9-12 can help develop an understanding of the abilities necessary to do scientific inquiry.

At the high school level, according to the NRC, students should be able to:

- 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 scientific explanations and model using logic and evidence,
- recognize and analyze alternative explanations and models, and
- communicate and defend a scientific argument. (NRC, 2000a, p. 19)

Although the *National Science Education Standards* have been “replaced” by *A Framework for K-12 Science Education* and the *Next Generation Science Standards*, science teachers should still become familiar with the *National Science Education Standards*. The Standards can be purchased in soft cover, read online, or downloaded as a free PDF version from the National Academy Press (www.nap.edu/bookstore). Readers may also be interested in an excellent accompanying text, *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning* (2000a) that offers stories of high school teachers engaging students in inquiry (see Resource A, the “Print Resources on Scientific Inquiry and Argumentation” section).

What *A Framework for K-12 Science Education* and the *Next Generation Science Standards* Say About Inquiry

In 2012, the National Research Council (NRC) published *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. According to the NRC (2012), the *Framework* identifies a general description of the science content and skill development that all U.S. students should be familiar with by the end of grade 12. The *Framework* also lays the foundation for the development of the *Next Generation Science Standards* in 2013.

Like the *NSES*, the *Framework* is not written at the level of specificity as grade-by-grade standards. Similarly, the *Framework* identifies and articulates the core ideas in science around which standards should be developed in life sciences, physical sciences, earth and space sciences, and engineering and technology. In addition to the core ideas, cross-cutting concepts and science practices are also identified and sequenced across the K-12 level. Each of these three dimensions of the *Framework* inaugurates the vision of the scope and nature of science education as a crucial aspect in fostering scientifically literate citizens for the 21st century. And like the *NSES*, inquiry, once again, plays a significant role in the advancement of scientific literacy.

(Note that in the *Framework* and the *Next Generation Science Standards* the term “practices” is used to represent the term “inquiry.”)

The “practices” identified in the *Framework* reflect certain common qualities to problem-solving and inquiry approaches. According to the NRC (2012), the practices in the *Framework* document reflect the work that scientists and engineers actually engage in as part of their work.

The eight essential practices of science include:

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, information and computer technology, and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Each of the eight essential practices are elaborated in greater depth in the original document. The *Framework*, however, makes a stronger commitment to the basis of developing claims and supporting evidence as a result of an inquiry investigation. In the *Framework*, scientific argumentation and reasoning play a central component in learning science. These two topics will be addressed in greater detail in Chapter 2, “Constructing an Understanding of Scientific Argumentation.” Readers are highly encouraged to become familiar with the *Framework* and the *NGSS* and their implications for inquiry-based teaching and learning. In the years ahead, scientific “practices” and argumentation will play an ever increasing role in the United States’ goal of achieving scientific literacy. *The Next Generation Science Standards* are poised to advance the next wave of guidelines to guide students to 21st century learning skills.

Inquiry as a 3-Legged Stool

From the readings we see that inquiry has a three-prong meaning. According to Flick and Lederman (2006), “inquiry stands for a fundamental principle of how modern science is conducted. Inquiry refers to a variety of processes and ways of thinking that support the development of new knowledge in science. In addition to the doing of science, inquiry also refers

to knowledge about the processes scientists use to develop knowledge that is the nature of science itself. Thus, inquiry is viewed as two different student outcomes, ability to do scientific processes and the knowledge about the processes” (p. ix).

The third prong of its meaning has to do with teachers using an inquiry approach as a means to teach students science content and the methods and processes scientists use. Flick and Lederman (2006) go on to say that “the logic here is that students will best learn science if they learn using a reasonable facsimile of the processes scientists follow” (p. x). Thus for effective inquiry instruction, science teachers need to balance both the understandings about scientific inquiry and the abilities in doing scientific inquiry.

In many ways, inquiry is like a 3-legged stool. Not only does it refer to the doing, knowing, and teaching aspect, it also involves the science, art, and spirit of curiosity. Inquiry can be further explained as the scientific process of active exploration by which we use critical, logical, and creative thinking skills to raise and engage in questions of personal interest. Driven by our curiosity and wonder about observed phenomena, performing an inquiry investigation usually involves several elemental aspects:

1. Generating a science-related question or problem to be solved, one that physically, mentally, and personally engages the student,
2. Brainstorming possible solutions to the question or problem,
3. Formulating a statement to investigate,
4. Designing an action plan and carrying out the procedures of the investigation,
5. Gathering and recording data through observation and instrumentation,
6. Organizing and analyzing the data for patterns and relationships among the variables,
7. Drawing appropriate and evidence-based conclusions, claims, and explanations from the data,
8. Connecting the explanation to previously held knowledge, and
9. Communicating the conclusions, claims, and explanations with others through scientific argumentation.

As we communicate and share our explanations, inquiry assists in (a) connecting our prior understandings to new experiences, (b) modifying and accommodating our previously held beliefs and conceptual models, c) providing opportunities for discourse, and (d) constructing new knowledge. In constructing newly formed knowledge, students generally are cycled back into the processes and pathways of inquiry with new questions and discrepancies to investigate.

Finally, learning through inquiry empowers students with the knowledge, skills, and attitudes to become independent thinkers. In many ways, it is a preparation for lifelong learning, fostering curiosity and creativity. Teachers can encourage students to use communication, manipulation, and problem solving skills to increase their awareness and interest in science, setting them on the path to becoming scientifically literate citizens. For science teachers, the inquiry approach requires a different mindset and expectations. At first, inquiry can be both seductive and intimidating to the novice teacher. As teachers come to understand the role they play in facilitating an inquiry-based classroom, the transition from a teacher-centered to a learner-centered classroom becomes promising. For this reason, rather than just providing a compendium of inquiry activities, this book principally emphasizes understanding the philosophical ideology and role-changing process considered necessary for inquiry instruction.

Seven Segments of Scientific Inquiry

Another approach to looking at the “flow” of a scientific investigation can be expressed through the Seven Segments of Scientific Inquiry (Llewellyn, 2011). Here we begin by dividing an investigation into three parts: the question, the procedure, and the results. In previous books by the author, this has been referred to as the Invitation to Inquiry Grid. Later in the book, Chapter 7 will introduce the Inquiry Grid in more detail. For now, let’s return to the three major areas and consider that these three areas can be further divided into seven segments, with each segment having its own set of performances and thinking skills. The seven segments include the following:

The Question

1. Exploring a Phenomenon
2. Focusing on a Question

The Procedure

3. Planning the Investigation

4. Conducting the Investigation

The Results

5. Analyzing the Data and Evidence
6. Constructing New Knowledge
7. Communicating New Knowledge

(Place Figure 1.1 here)

The purpose of providing the Seven Segments is threefold. First, it provides a suggested sequence of cognitive skills and performances for a scientific inquiry. By becoming familiar with the Segments, teachers are better able to articulate the concept and process of a science inquiry. Although the Segments may seem to be a lengthy set of sequential “steps”, they should not be interpreted as an embellishment of the scientific method or prescribed rungs on a ladder. The Seven Segments serve as a way to capture the essential aspects of an inquiry investigation.

Second, the Segments provide a blueprint for designing your own science investigations. It is expected that at the end of this book you will feel competent in modifying your present longstanding traditional labs as well as designing your own original inquiries. In the development of your own inquiries, many, if not all, of the segments will be represented, in one way or another, in your design.

Third, the Segments serve as an assessment vehicle to judge how well a particular lab demonstrates the qualities of an effective inquiry-based science investigation. Whether you use it as a general guide or a checklist, a good number of the performances and thinking skills listed under each Segment should be evident in a science investigation. As you read the case studies in this book, occasionally flip back and review the seven segments. Make a mental note of how each segment is applied in the example. Also, as you design your own inquiries later in the book, use the progression of segments to guide the construction of your own investigations.

The Pretzel Theory of Science Inquiry

Throughout this book we will see that not all science inquiries are alike. Some inquiries are short and straightforward. Others may be short with several twists and turns. Similarly, other inquiries can be lengthy yet still straightforward; while still others may be like a roller coaster - long-

lasting with loads of loops and zigzags. Think of the different variations of science inquiry as pretzels. There are small, rod-shaped pretzels and long rod-shaped pretzels. There are small twisted pretzels and large twisted pretzels. Well, you get the analogy. The point is - although you may start off your school year by having students do short, straightforward inquiry investigations, with a little practice and patience they will soon be performing the entire set of the Seven Segments' manipulative and thinking skills. And for you, the journey in becoming an inquiry-based teacher will test the limits of your creativity.

Inquiry as a Human Endeavor

Although the seven segments offer a “progression” for testing assumptions, collecting data, and forming explanations, the observations made, the claims stated, and evidence provided through student inquiries are seldom identical. Even for practicing scientists there is seldom just one correct way to conduct an experiment. Spurred by their inquisitiveness, high school students' explanations are largely based on their a priori experiences and expectations of the assumption being explored. It is possible that two biology students can conduct the same science inquiry about the local environment yet draw different inferences, claims, and explanations from the same set of data. In this sense, both sorting evidence and constructing explanations becomes a personal matter. As stated in the *Benchmarks for Science Literacy*, the American Association for the Advancement of Science says, “what people expect to observe often effects what they actually do observe” (AAAS, 1993, p. 12).

Furthermore, the NRC states, “Science is very much a human endeavor, and the work of science relies on basic human qualities, such as reasoning, insight, energy, skill, and creativity - as well as on scientific habits of mind, such as intellectual honesty, tolerance of ambiguity, skepticism, and openness to new ideas” (NRC, 1996, p. 170). As high school teachers guide their classes through science inquiries, it is crucial to remind students to keep accurate records of their work in the interest of objectivity. Some students may experience varying difficulties being entirely objective about their work. They tend to choose information as evidence to support their point of view. To help thwart sources of bias, the accurate collection of data and information is invaluable in supporting claims that are backed with evidence, logical arguments, and critical reasoning (AAAS, 1993). Throughout the inquiry process, students in grades 9-12 should be encouraged to exhibit skepticism and act as a “reflective friend” in critiquing each other's

conjectures and suppositions. Only through the analysis and examination of each other's work can students truly appreciate the real work of scientists, the essence of inquiry, and the evolving nature of science.

Ten Beliefs (and Rebuttals) About Inquiry-Based Learning

To this point, we have been learning what inquiry is. Now, we want to turn our attention and address ten conceptions (or misconceptions) high school science teachers, who are inexperienced with inquiry, often make about this approach to teaching and learning. To introduce the argument process, a rebuttal follows each belief statement.

Belief #1: I have students do many hands-on labs as part of my science course. To me, that's doing inquiry.

Rebuttal: Providing students with an opportunity to do labs especially those with hands-on activities, does not necessarily mean they are doing inquiry. Many lab and textbook activities can be highly structured. These labs usually provide the students with the question to investigate, what materials to use, and most of all, how to go about solving the question by listing a sequence of step-by-step procedures of the lab. In many cases, commercially produced labs even provide a chart or table for the students to record their observations, measurements, or data. These types of labs are often referred to as "cookbook" because they provide a systematic procedure and follow a very linear path to a solution to the question. This is not to say that these kinds of lab experiences are not important, or that high school science teachers should avoid using them, but many traditional and structured labs are not true inquiry. Although most inquiry labs and activities are hands-on, not all hands-on labs and activities are inquiry oriented.

Belief #2: I am, what many would consider, a traditional teacher and my students do pretty well. My style works for me, especially since there is no research that indicates teaching through inquiry improves student achievement.

Rebuttal: The National Science Foundation (NSF) funded Inquiry Synthesis Project synthesized findings from research conducted between 1984 and 2002 to address the research question - What is the impact of inquiry science instruction on K-12 student outcomes? Over 130 analyzed studies indicate a clear, positive trend favoring inquiry-based instructional practices, particularly

instruction that emphasizes student active thinking and drawing conclusions from data.

According to the project investigators, teaching strategies that actively engage students in the learning process through scientific investigations are more likely to increase conceptual understanding than are strategies that rely on more passive techniques. For the project's analysis see: Minner, D., Levy, A., & Century, J. (2009). Inquiry-Based Science Instruction-What Is It and Does It Matter? Results from a Research Synthesis Years 1984 to 2002. *Journal of Research in Science Teaching*, 47(4), 474–496 or go to:

<http://onlinelibrary.wiley.com/doi/10.1002/tea.20347/pdf>

Belief #3: I observed a high school science classroom where students were learning through inquiry and the lesson appeared to be unstructured and open-ended. That's not what I think good teaching is all about.

Rebuttal: In some high schools, a good teacher is perceived as one who keeps a classroom quiet and students consumed in seat time. Although no one will argue that effective classroom management skills are essential for inquiry learning, an active, student-centered classroom should not be equated with chaos or unstructured instruction. Just like during any lab activity, when students do inquiry-based science we can expect the noise level to raise somewhat. To some, inquiry may appear on the surface to be unstructured and open-ended, but as student involvement increases, so does the need for the teacher to manage classroom movement and communication. When teachers use inquiry-based strategies, they may find that teaching requires more preparation and anticipation of possible student questions than traditional labs and teaching approaches do.

Teachers new to inquiry may often feel less in control when students move about the room, make decisions about their work, and are encouraged to challenge the work of others. Although most teachers are actually in control, they perceive otherwise. To establish inquiry-centered environments, teachers need to accept changes in their role and in the atmosphere and environment of the classroom. In Chapters 8 and 9 we will see how good classroom management and questioning skills are a prerequisite for creating a culture of inquiry. Without good classroom management, any lab, including an inquiry-based lab, will result in a chaotic situation.

Belief #4. During my class lectures and discussions, I ask students a lot of questions. To me, that's one form of inquiry.

Rebuttal: Although valuing questions is a basic commonality in an inquiry-based classroom, the misconception held by some high school science teachers is that inquiry teaching requires that the teacher asks a lot of questions. We might recall our own experiences sitting in science lectures where the teacher fired off question after question. Asking a lot of questions does not necessarily make an inquiry lesson. If you ever saw the 1973 movie classic, *The Paper Chase*, and watched how Professor Kingsford (played by John Houseman) used his version of the Socratic Method to “drill” and intimidate his first-year law students, you know that questions can be a double-edge sword. In Chapter 9 we will see several examples of effective questioning strategies that support inquiry settings. In inquiry-centered classrooms, teachers provide both expository and exploratory questions to foster critical thinking and problem solving.

Belief #5: I am under the impression that any science lesson can be taught through inquiry.

Rebuttal: On the contrary, the fact is, a good part of the core ideas in science, especially in the high school grades, are best learned through traditional, didactic methods such as lectures, presentations, simulations, and textbooks. Some science lessons, because of safety reasons or availability of materials, lend themselves to more structured, teacher-centered settings than others. Some labs in chemistry and physics do not provide flexibility in the procedure section. As teachers, we decide which lessons are best presented through direct instruction or a teacher-led approach, and which ones can be guided through inquiry.

Belief #6: Inquiry may be appropriate for elementary and middle school students, but I can't teach through inquiry when I am expected to get students ready to pass a final exam at the end of the course. With a high-stakes test looming over my head, I do not have time for inquiry in my college-prep courses.

Rebuttal: For many high school science teachers, lecture and discussion are the primary means to dispense knowledge to their students. These teachers see lecturing as the most effective and efficient way to transmit large amounts of content information to their students in a relatively short period. Lecturing is also the method by which many teachers learned science when they were in high school. It is also a method by which many teachers learned science when they were

studying to become science teachers. So, based on prior experience, we should not be surprised that so many science classes are lecture-based.

High school science teachers often talk about the time constraints they feel they operate under (although the *Next Generation Science Standards* emphasizes less breadth and more depth). With more and more concepts being added to the curriculum, many science teachers say they are pressed to “cover” the curriculum in a school year (remember, cover means to obscure from view). It is true that inquiry-based learning takes more time, however, having students pose questions, plan solutions, gather and analyze data, and defend their findings are higher level thinking abilities that are only nurtured over time. There are no shortcuts to developing students with critical thinking skills.

I once was told the story about a physics teacher who routinely used the first five minutes of class to take attendance and the last five minutes of class to provide students an opportunity to start on their homework. If you were to multiply 10 minutes a day by 180 days per school year, you can see that this particular teacher used 1,800 minutes a year, or 36 50-minute periods, on non-instructional procedures. In addition, this same teacher taught a 5-day unit on the latent heat of vaporization that was not part of the district’s physics curriculum. To find time to do inquiry or to create an inquiry-based curriculum, teachers need to utilize their time effectively and efficiently while centering on topics and concepts at the core of the curriculum.

Belief #7: You can’t assess inquiry-based learning like you can science concepts and facts.

Rebuttal: Inquiry-based learning can be assessed like any other concept or topic in science but teachers need to use alternative methods of evaluation. Popular objective-type multiple-choice questions do not always adequately assess inquiry-based learning. To assess students’ academic progress, inquiry-based teachers often rely on supplementing traditional assessments by using portfolios, writing journal entries, extended response questions, self-evaluations, and rubrics in conjunction with objective-type questions. Examples of each of these alternative, authentic assessments will be presented in Chapter 9.

Belief #8: I have been teaching high school science for almost 20 years and have seen a lot of “bandwagons” come and go in my lifetime. Scientific inquiry and argumentation seems to be the latest thing for science education.

Rebuttal: Actually inquiry and argument-based instruction has an enduring historical significance in science education. Those who study the history of science education know that questioning, discovery learning, and inquiry date back to the early days of the Greek scholar, Socrates. The progressive education reformer John Dewey is credited as one of the first American educators to stress the importance of discovery learning and inquiry. In his early work, Dewey proposed that learning does not start and intelligence is not engaged until the learner is confronted with a problematic situation. His work at the University of Chicago paved the way for curriculum reform in science.

Yet despite the overwhelming recommendations from national committees and leading educational reformers in science education, little was done to implement inquiry into America's classroom in the early 1950s. It wasn't until October, 4, 1957 when Russian scientists launched a 184 pound satellite with four whisker-like antennas that circled the Earth every 92 seconds at the speed of 18,000 mph that sparked science curriculum reform efforts. Sputnik, as the Russians called it, was a devastating blow to the American psyche. Although President Eisenhower downplayed the incident, it exposed our technical weaknesses and wounded our national pride. That event led to the formation of the National Defense Education Fund in 1958 to support numerous elementary and secondary school science programs that emphasized inquiry-based instruction. From 1958 through the mid-1960s is what some call the golden age of science curriculum in the United States.

Working with John Dewey at the laboratory school at the University of Chicago during the 1960's, another reformer, Joseph Schwab, advocated that science curriculum should model how science gets done. Schwab encouraged curriculum reformers to design science programs that downplay science as dogma and target the design of investigations, the analysis of data, and the explanation of evidence through argumentation, as an essential role for students learning science.

Today, on the high school level, premier biology programs like the Biology Sciences Curriculum Study (BSCS) are deeply rooted in instructional methods of learning that stress the importance of inquiry-based instruction and communicating newly-learned knowledge through discussion and argumentation. In addition, inquiry and argumentation has been and continues to be the philosophical foundation for many NSF and National Science Teachers Association (NSTA) sponsored curriculum projects in biology, earth science, chemistry, and physics. As

state, district, and school level science departments implement the practices, crosscutting concepts, and the core ideas of *Next Generation Science Standards*, inquiry and argument-based teaching and learning will play a principal role in the formation of K-12 science curricula over the next 20 years. So is inquiry and argumentation a “bandwagon” or fad? Absolutely not.

Belief #9: I perceive inquiry as “soft science” and not content related.

Rebuttal: Inquiry, according to the NSF and the National Academy of Science, is one of the core concepts identified as content-related. That elevates inquiry to the same level as knowing the concepts, principles, laws, and theories about the life, earth, or physical sciences. According to the AAAS (1990), “science teaching that attempts solely to impart to students the accumulated knowledge of a field leads to very little understanding and certainly...science teachers should help students to acquire both scientific knowledge of the world and scientific habits of mind at the same time” (p. 203).

If students are to gain an appreciation for science and compete in the scientific and technically-oriented society of the new millennium, they will need a curriculum that promotes active learning, critical thinking, and ways to solve tomorrow’s questions. Inquiry-based science is a proven means to enhance scientific literacy. Additional research has led to the conclusion that inquiry promotes creativity, critical thinking skills, and positive attitudes towards science. Although inquiry is no panacea, it is one more strategy teachers can have in their instructional toolbox to engage students in investigations and satisfy their curiosity for learning.

Belief #10: I admit, inquiry is a good way to teach science. I like giving my students inquiry-based labs, however, they seem to be best for high achieving, college-bound science students. My basic students with learning disabilities have trouble learning through inquiry.

Rebuttal: The recommendations set forth by both the NRC (1996) and the *Framework* (2012) apply to all students regardless of age, cultural or ethnic heritage, gender, physical, or academic ability, interest or aspirations. The national standards stress that the recommendations apply in particular to those who have historically been under-represented in the fields of science and engineering; mainly students of color, females, limited English proficiency students, and those considered high-need. According to the *Standards*, “given this diversity of student needs, experiences, and backgrounds, and the goal that all students will achieve a common set of

standards, schools must support high-quality, diverse, and varied opportunities to learn science” (NRC, 1996, p. 221). The ability to think creatively and critically is not solely for the high-achieving student. Inquiry-based instruction can and must be done equitably at all levels. In contrast, some teachers argue that it’s the general level students who seem to succeed best by learning through inquiry. Many of those same teachers claim that it’s the high achieving students who always what to be given the correct answer.

What Science Inquiry Is - What Science Inquiry Isn’t

Here’s an activity to do. Working with a partner or in a small group, place a poster-size sheet of paper on a wall. Using a marker, make a T-chart like the one shown below. Label the left hand column “What Inquiry Is” and the right hand column “What Inquiry Isn’t”. (For larger groups, you may want to use two separate poster sheets.)

(Place Figure 1.2 here)

Give each participant a pad of medium size adhesive notes. Tell each of the participants to write a statement on a sticky note that describes what inquiry is or isn’t. And then place that sticky note on the appropriate column of the T-chart. After 10 minutes, the poster sheets should be filled with sticky notes. Next, read all the sticky notes aloud, one at a time. Take off any duplicate statements. Have a discussion about the statements. Were there any statements you would not agree with? Did the activity expose any misconceptions about inquiry? Compare the groups posting with the statements about inquiry from the 1996 national standards or the Framework that you read earlier in this chapter.

A Definition of Scientific Inquiry

From the chapters that follow, we will discover scientific inquiry as the process of active exploration by which we use critical, logical, and creative thinking skills to raise and engage in questions of personal interest. It is the dynamic collaboration between the individual investigator and the question being investigated. Driven by students’ curiosity and wonder about observed phenomena, inquiry investigations usually involve

- generating a question or problem to be solved,
- brainstorming possible solutions to the problem,
- stating a single or multiple hypotheses to test,

- choosing a course of action and carrying out the procedures of the investigation,
- gathering and recording the data through observation and instrumentation to draw appropriate conclusions, and
- communicating and justifying their claims and evidence through scientific argumentation.

As high school science students communicate and defend their explanations, inquiry helps them connect their prior understandings to new experiences, modify and accommodate their previously held beliefs and conceptual models, negotiate meaning (Hand, et al., 2009), and construct new knowledge. In constructing newly-formed knowledge, students generally are cycled back into the processes and pathways of inquiry with new questions and discrepancies to investigate.

During the investigation throughout this book, you will read about students exhibiting the five essential features of scientific inquiry:

- Learners are engaged by scientifically-oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically-oriented questions.
- Learners formulate explanations from evidence to address scientifically-oriented questions.
- Learners evaluate their experiences in the light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations. (NRC, 2000a, p. 35)

Finally, learning through inquiry and argumentation empowers high school science students with the knowledge, skills, and dispositions to become independent thinkers and lifelong learners. The process encourages students to use communication, manipulation, and problem-solving skills to increase their awareness of and interest in science and guide them on their way to becoming scientifically literate citizens.

An inquiry approach requires a different teacher “mindset” and classroom culture for creating a learner-centered environment. In Chapters 4 and 5, you will read more about

becoming an inquiry-based science teacher and how a constructivist mindset parallels inquiry. Then in Chapter 6, you will read about the role high school science teachers play in crafting a culture of classroom inquiry.

Questions for Reflection and Discussion

At the end of a chapter in many professional development books the author provides questions for further discussion. Contrary to this and to model good inquiry, the questions should come from you. So whether you are reading this book alone, collaborating in a small study group, or participating in a college course or summer institute, write three questions you presently have about inquiry. The questions may be about the challenges you face in implementing science inquiry in your school or a reaction to a section you read in Chapter 1. This exercise is designed to evoke thoughts, opinions, viewpoints, and most of all, personal feelings about what you are reading. After you write your three questions, share them with others also reading this book. Set a few moments aside, maybe over coffee or pizza, to answer each question. Your questions, responses, and reflections will become beneficial as you progress on your journey.

Three questions I have are:

- 1.
- 2.
- 3.

If you cannot think of any questions to pose or do not have any questions this early in the book, you can start a journal to record your reflections over the next few months. Begin by writing your definition of inquiry. Prepare a written narrative, a set of bullets, or even a concept map to capture your present understandings of science inquiry. Compare your understandings to the sections you previously read from the national organizations. Consider writing about how you think inquiry promotes scientific literacy and the kinds of knowledge, skills, and attitude your students will need to succeed beyond their high schools years.

If you are familiar with Howard Gardner's theory on Multiple Intelligences, you can write how inquiry-based learning supports a naturalistic intelligence. Or you can think about how teaching through inquiry (versus teaching about inquiry) supports students to understand the nature of science. Think about where your science instruction is presently and where you want it be a year from now, three years from now, five years from now. Regardless of the path you take,

it is essential to articulate and document your ideas about inquiry. As you progress through this book, frequently return to your writing and revise your understanding. By adding new thoughts to your definition or scrapping ideas that you now think are outdated, you can make modifications to your evolving notion of inquiry.

The following quote is from *Interdisciplinary Inquiry in Teaching and Learning, 2nd edition* by Marian Martinello and Gillian Cook. How does the analogy of ripples on a pond complement your understanding of inquiry?

“The pebble that drops into a pond is like an idea that sparks inquiry. The concentric ripples represent new questions that emerge from the first germ of the idea. The ever-enlarging pattern of ripples refer to the integrated knowledge that is acquired as each question is explored, limited only by the force of the inquirer’s enthusiasm for the search. The greater the interest and the more probing the questions, the more encompassing the study, the bigger the ideas that it develops, and the deeper and more meaningful the knowledge the inquirer constructs.”