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Teaching Science as Inquiry

Science literacy—the ability to use one's knowledge and understanding of science concepts and processes to solve realistic problems and issues for personal and social benefits[1]—has become a necessity for everyone because the society in which we live is increasingly dependent on science and technology. Despite the centrality of science to the quality of our life and to the progress of our society, many students fail to acquire even the most rudimentary science concepts, skills, and abilities. According to the 2005 National Assessment of Educational Progress (NAEP) science assessment, for example, 32% of fourth graders, 41% of eighth graders, and 46% of twelfth graders perform below the Basic level; less than one-third of the students in Grades 4 (29%), 8 (29%), and 12 (18%) perform at or above the Proficiency level; and very few students in Grades 4 (3%), 8 (3%), and 12 (2%) perform at the Advanced level.[2] International comparisons, such as the Trends in International Mathematics and Science Study (TIMSS), also indicate that the U.S. students in Grades 4 and 8 lag behind their international counterparts in some Asian and European countries in terms of both content and the set of cognitive behaviors (such as knowing, applying, reasoning) needed for successful engagement with the content.[3] A recent research synthesis by British researchers Osborne, Simon, and Collins found that students' attitudes toward science begin to decline in the upper elementary grades, and this decline accelerates rapidly after middle school (that is, from age 14 years onward).[4] Noted science educator and scholar Jay Lemke summed up the plight of science education in American schools this way:

> Too many pupils care less and less for science as a school subject the more they've taken. Too often, with the best intentions, our teaching of science frustrates students who know we expect them to understand, but who also know that they don't (even when they seem to).[5]

This disturbing state of science education has serious consequences for the preparation of a capable scientific and technological workforce, threatening to unravel the U.S. economy and undermine its global leadership. In response to the situation, the science education community has launched a series of reform initiatives aimed at improving science teaching and learning. One major reform initiative focuses on making inquiry the cornerstone of the science education curriculum.[6] Another significant strand of the recent science education reform effort is to encourage the use of language and literacy practices in support of science teaching and learning.[7] These two reform initiatives are discussed next.

INQUIRY-BASED SCIENCE

What Is Inquiry-Based Science?

During the past 15 years or so, the National Research Council and the American Association for the Advancement of Science (AAAS) have issued calls for reform in science education and published important documents to guide this reform. Among their publications, the *National Science Education Standards*[8] and *Benchmarks for Scientific Literacy*[9] are perhaps the most influential. Both documents recommended the enactment of a science curriculum that embraces an inquiry-oriented approach to science teaching. According to the National Research Council, scientific inquiry is

> a multifaceted activity that involves observation; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations and predictions; and communicating the results.[10]

Inquiry-based science recognizes science as a process of discovery and invention that involves engagement, exploration, explanation, application, and evaluation. It emphasizes developing the ability and disposition to investigate, constructing knowledge and understanding through active learning, attaining specific science process skills, and communicating scientific explanations and arguments.[11] More specifically, inquiry-based science aims to develop the following student outcomes:

> appreciating the diverse ways in which scientists conduct their work; understanding the power of observations; knowledge of and ability to ask testable questions, make hypotheses; use various forms of data to search for patterns, confirm or reject hypotheses; construct and defend a model or argument; consider alternative explanations; and gain an understanding of the tentativeness of science, including the human aspects of science, such as subjectivity and societal influences.[12]

In outlining what students should know, understand, and be able to do over the course of their K–12 education, the *National Science Education Standards* makes the point that inquiry is a step beyond the traditional process approach that focuses on lecture and demonstration. Inquiry-based science shifts the focus of science education from the accumulation of facts and the development of decontextualized science process skills to the provision of experiences that foster the development of scientific knowledge, skills, and habits of mind. It embraces the constructivist view that students learn best by doing and by active engagement. It requires students to identify assumptions, use critical and logical thinking, and consider alternative explanations.[13] Through inquiry, students learn to use scientific knowledge and processes as well as critical thinking and reasoning skills in formulating and addressing their questions. They also develop a deeper understanding of the nature of science and scientific processes as a result of their active involvement in exploring, explaining, and debating science-related phenomena and issues.

Why Inquiry-Based Science?

An inquiry-based approach shifts the focus of science teaching and learning from an interest in the accumulation of facts and concepts to the processes that engage students in actively seeking answers to their own questions or to the questions raised by others. It emphasizes the processes that scientists value for generating, validating, and renovating knowledge. As students become involved in asking questions and seeking answers, their interest in the subject will also increase. Such an engagement in the processes of science bolsters not only students' understanding of how science knowledge is constructed but also their development of scientific abilities and habits of mind.

According to the *National Science Education Standards,* a scientifically literate person is someone who

- can ask, find, or determine answers to questions derived from curiosity about everyday experiences;
- has the ability to describe, explain, and predict natural phenomena;
- is able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions;
- can identify scientific issues underlying national and local decisions and express opinions that are scientifically and technologically informed;
- is able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it; and
- has the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.[14]

Inquiry-based science is a powerful vehicle for developing such individuals. It promotes understanding about the nature of science, the acquisition of scientific knowledge and skills, and the cultivation of scientific habits of mind. It enables students to learn science content and use scientific understanding to make informed decisions about personal and social issues. Effective inquiry-based experiences can also help demystify some of the beliefs about science and scientists and entice more students into advanced studies in the science fields.

Several syntheses of empirical research on science teaching suggest that inquiry-based science has a positive effect on students' attitudes toward science, science achievement, cognitive development, science process skills, and understanding of science concepts.[15] For example, Wilson, Taylor, Kowalski, and Carlson designed a laboratory-based randomized control study to investigate the effectiveness of inquiry-based instruction in developing adolescent students' (aged 14–16 years) science knowledge, reasoning, and argumentation. The researchers reported that the students in the inquiry-based group reached significantly higher levels of achievement than the students experiencing commonplace, or traditional, instruction across a range of learning goals (knowledge, reasoning, and argumentation) and time frames (immediately following the instruction and four weeks later).[16] Chang and Mao compared the effects of inquiry-based instruction versus traditional teaching methods on ninth-grade students' achievement in and attitudes toward earth science. They found that the students who received inquiry-based science instruction scored significantly higher on a knowledge-based earth science content test and developed more positive attitudes toward the subject than their peers who received traditional methods of science instruction.[17] Dalton, Morocco, Tivnan, and Mead examined the effects of two approaches to hands-on science on fourth-grade students' science learning. One approach, called supported inquiry science (SIS), focused on eliciting and reworking students' misconceptions (or alternative conceptions) and coconstructing knowledge under the guidance of a teacher-coach. The other approach is called activity-based science (ABS). The researchers found that the students (with and without learning disabilities) in SIS classrooms demonstrated greater concept learning than their peers in ABS classrooms.[18]

Taken together, these studies show that an inquiry-based approach to science teaching is more effective than traditional, or commonplace, approaches in developing students' interest in and knowledge about science and in promoting their science inquiry skills and habits of mind. As Hmelo-Silver, Duncan, and Chinn concluded, "there is growing evidence from large-scale experimental and quasi-experimental studies demonstrating that inquiry-based instruction results in significant learning gains in comparison to traditional instruction and that disadvantaged students benefit most from inquiry-based instructional approaches."[19]

Translating Inquiry-Based Science Into Classroom Practice

Science teachers know the importance of inquiry, but many lack a practical framework for teaching science as inquiry to guide their instruction.[20] They face a multitude of challenges in enacting the concept of inquiry-based science in classrooms and schools.[21] These challenges include

- how to overcome technical (the meaning of inquiry), political (state mandates), contextual (school culture, resources), and personal (prior beliefs, experiences, knowledge, preference, motivation) barriers that impede the enactment of inquiry;

- how to help students formulate questions that can lead to meaningful inquiry;
- how to translate these questions into experiments and activities that extend students' conceptual understanding;
- how to guide students to make evidence-based decisions; and
- how to develop students' competence in communicating scientific findings and understanding.

As a result of these and other challenges, inquiry-based teaching remains uncommon in science classrooms.[22]

While the *National Science Education Standards* presents several vignettes of how inquiry could be enacted in the science classroom, it does not operationally define inquiry-based instruction. However, it does identify five essential features of inquiry-based science classrooms that can be used to guide instruction. These five features, along with their interpretations, are summarized below:

1. *Students are engaged by scientifically oriented questions.* These questions should be possible to investigate and aimed at probing the origins, causes, and processes related to objects, organisms, events, and relationships in the natural world.

2. *Students give priority to evidence in responding to these questions.* Students obtain accurate evidence through repeated observations and careful measurements in natural settings (like prairies or beaches) or contrived settings (like labs). They also obtain evidence from secondary sources such as teachers, textbooks, trade books, or websites. All evidence is subject to verification, questioning, and further investigation.

3. *Students formulate explanations from evidence.* Explanations are based on logic and reasoning, instead of personal beliefs, religious values, myths, or superstition.

4. *Students evaluate their explanations in light of alternative explanations.* Students learn about other possible explanations through sharing with peers and reading related materials. This process should lead students to refine or reconsider their own explanations based on the available evidence.

5. *Students communicate and justify their explanations.* Students demonstrate the ability to articulate their questions and hypotheses, describe investigative procedures and the experimental evidence, present plausible explanations, and develop logical arguments based on an examination of existing scientific knowledge.[23]

Sample strategies for incorporating these features into the science classroom are presented in Table 1.1.

Table 1.1 Strategies for Incorporating Essential Features of Inquiry Into Science Classrooms

Essential Features of Inquiry	Teaching Activities
Engaged by scientifically oriented questions	• Provide opportunities for students to observe and explore their surroundings, which should lead them to generate questions about the natural world. • Have students read relevant texts and use the reading as a springboard to get students to raise and discuss relevant issues and questions. • Guide students to reframe or reword their questions or wonderings into forms that can be investigated. • Work with students to turn the purposes or objectives of traditional science activities into research questions.
Give priority to evidence	• Give students opportunities to identify variables, develop procedures, and devise strategies for collecting and presenting data. • Engage students in data analysis through a search for patterns and themes.
Formulate explanations from evidence	• Encourage students to construct explanations based on the experimental evidence. • Discuss with students that explanations based on personal beliefs or religious values may be interesting, but are not scientific.
Evaluate explanations	• Introduce information from the text and engage students in comparing and contrasting their own explanations with those provided in the text or offered by their peers.
Communicate and justify proposed explanations	• Encourage students to talk with their peers about their inquiry. • Provide opportunities for sharing through written and oral presentations. • Involve students in debates. • Allow students to challenge their own explanations and those of their peers.

The implementation of the five essential features of inquiry does not have to proceed in a linear fashion. Depending on the goals of the curriculum and the students' level of cognitive development, teachers can vary the ways in which these essential features are included and developed in the classroom; they can also adjust the level of inquiry during instruction. For example, teachers can choose to focus on developing students' abilities to formulate scientifically oriented questions in a particular science activity. If, however, the focus of the activity is on formulating explanations from evidence, teachers can guide students in collecting data, analyzing data, and generating explanations based on the experimental evidence. In some cases, students may need to develop the skills of observation and measurement and be able to manipulate experimental instruments before they can effectively collect and record data. Understanding variables and principles of "fair testing" (that is, making sure only one factor, or variable, is changed at a time while keeping all other conditions the same) is also important and should be considered when planning for inquiry-based science. Above all, classroom investigations should be guided by concepts, performed not only to verify rules but also to test ideas, and aimed at developing students' skills to think logically and critically about the relationships among evidence, claims, warrants, and explanations.[24]

Teaching science as inquiry places new demands on teachers. It requires them to go beyond their traditional role as knowledge transmitters to forge collaborative partnership with their students. Barbara Crawford proposed a model of inquiry teaching that embraces the following six characteristics: contextualize instruction in authentic problems, focus on grappling with data, forge collaboration between teacher and student, make connections with society, model behaviors of scientists, and develop student ownership.[25] This model embraces inquiry as both content and pedagogy and calls for active and complex teacher participation. It requires teachers not only to serve as knowledge facilitators or guides, but more importantly to engage students in the kinds of cognitive processes and behaviors used by practicing scientists. This means that the level of teacher involvement in inquiry-based classrooms is significantly greater than in traditional classrooms.

In teaching science as inquiry, teachers can vary the level of inquiry—and thus the amount of support they provide to students—on a continuum from a more structured, teacher-controlled format to more open-ended explorations initiated by students. Because it takes time for students to develop the confidence and skills needed for doing inquiry, teachers need an incremental approach when transitioning to a more extensive inquiry-based science curriculum. Ideally, teachers should tailor inquiry lessons to the readiness and developmental levels of their students. They can gradually increase the level of inquiry by moving along the following continuum:

- *Level 0 (No Inquiry):* Provide the problem, procedures, and methods to students and have them conduct an experiment to confirm a principle in which the results are known in advance.
- *Level 1 (Low Level of Inquiry):* Have students investigate a problem presented by the teacher using procedures and methods provided by the teacher. Students interpret the data and propose viable solutions to the problem.
- *Level 2 (Moderate Level of Inquiry):* Have students investigate a problem presented by the teacher using procedures and methods they choose or develop. Students decide what data to collect, how to interpret the data, and what explanations or solutions to propose for the problem.
- *Level 3 (High Level of Inquiry):* Have students investigate a problem they generated from a "raw" phenomenon using procedures and methods they choose or develop. They decide what data to collect, how to interpret the data, and what explanations or solutions to propose for the problem.[26]

Understanding that inquiry can be implemented with increasing student responsibilities allows teachers to offer the appropriate scaffolds needed to develop target knowledge, skills, and habits of mind.

Sample Inquiry-Based Science Lessons

To illustrate the principles of inquiry-based science, we provide two sample lessons (see Figure 1.1 and Figure 1.2) in which students were engaged in both hands-on (firsthand) and minds-on (secondhand) tasks of inquiry.

The inquiry-based approach as depicted in Mrs. Kaplan's and Mr. Bellamy's lessons reflects what has recently been recommended by the science education community and is believed to be most effective in developing students' scientific literacy. Like scientists who develop their knowledge and understanding as they seek answers to questions about the natural world, the students in both classrooms actively and collaboratively engaged in the "sciencing cycle" of recognizing a problem; formulating an investigatable question; proposing

Figure 1.1 An Inquiry-Based Science Lesson on Rocks

Exploring Rocks

The fourth graders in Mrs. Kaplan's class were seated in a circle on the floor for the usual morning meeting. It was the first day after spring break, and Mrs. Kaplan's plan was to have each student share an interesting event from his or her experience during the previous week. Payton was the second student to share. He pulled a plastic baggie from his backpack and placed it on the floor. "I went to a beach in California and I collected these rocks," he said. The teacher had Payton pass the collection around and everybody in the class took a rock to look at more carefully. "Wow! Mine has different colors," Madison screamed. "Mine too," echoed Jayda, who liked to write poems about rocks. "Look at the shape of this one," Diego said. Mrs. Kaplan was so excited about what the children had to say about rocks that she allowed an extra five minutes for them to share their observations. She knew that her lessons on minerals and rocks before the break had rubbed off on the children.

As the children continued to talk amongst themselves about rocks, Mrs. Kaplan drew three columns on the board and labeled them K (what I Know), W (what I Want to know), and L (what I have Learned). (This is called a K-W-L chart.) She instructed the children to go back to their seats and think about some things they already knew about rocks. After a few minutes, she asked, "Ok, so what do we know about rocks?" The children shouted a barrage of responses, including "They are hard," "There are different types," "Small rocks come from bigger ones," and "Rocks can make dirt." The teacher wrote these responses on the board, in the column labeled K.

"What questions do you have about rocks?" Mrs. Kaplan asked next. As the children responded, she recorded their questions on the board in the second column, labeled W. Some of the questions she recorded were "How are rocks made?" "Where do rocks come from?" and "How many different types of rocks are there?"

Mrs. Kaplan then divided the class into teams of four and gave each team a hand lens and a box of rocks she had procured in preparation for the science unit. She wrote the word *classify* on the board and held a discussion about what the word means. When she was sure that the children understood that *classify* means organizing things into groups based on similarities and differences, the teacher instructed the class to begin observing the rock collection in their box. She reminded the class of the procedures for appropriate use of a hand lens in making observations and then underlined the question "How many different types of rocks are there?" on the board. She asked the children to note in their science journals the colors and textures of their rocks, whether there were grains or crystals in the rocks, and what clues they could see that indicated how the rocks were formed. The children were to organize their rocks into groups and write down the features they used in separating them.

After fifteen minutes, Mrs. Kaplan had each team share what they did with their rocks. Four of the six teams classified their rock collections into three groups. The other two teams reported that they had classified their rocks into four groups. Mrs. Kaplan conducted a whole-class discussion, asking the children what features they used to classify the rocks. As each feature was identified, she strategically wrote it on one of the three chart papers she had previously taped to the wall. She then distributed a set of six books to each of the four teams that had organized the rocks into three groups, instructing them to pick a book to read and find the answer to the question "What are the three types of rocks?" She reminded students to use the table of contents or index in the books to look for the information they needed. The six books that Mrs. Kaplan handed out were *Rocks* by Alice Flanagan[27], *Rocks and Minerals* by Ruth Chasek[28], *A Look at Rocks* by Jo S. Kittinger[29], *Rocks and Minerals* by R. F. Symes[30], *Rocks Tell Stories* by Sidney Horenstein[31], and *Rocks and Minerals* by Herbert S. Zim and Paul R. Shaffer[32]. These books had been purposefully chosen to accommodate different reading levels among the students.

Mrs. Kaplan then went to the other two teams and guided the children in making further observations of the rocks. Soon, a consensus was reached among the members of the two teams that their rocks should have been separated into three groups, at which time the teacher handed each team the same set of six books and instructed them to read and respond to the same question (that is, What are the three types of rocks?).

There was a buzz in the room as the children began to figure out the three types of rocks. They were now eager to say and write the names on the chart paper on which the features were written. Three children were allowed to write the words, *igneous, sedimentary,* and *metamorphic* on the respective chart paper corresponding to the features. Mrs. Kaplan then challenged the class to classify the piece of rock they were given from Payton's collection and explain the reasons for their decisions.

As a homework assignment for the week, Mrs. Kaplan asked the children to pick two or three books to read at home from the trade book collection on rocks and minerals that she had checked out from the school and county libraries. All students were required to bring the notes they took during reading to help their teams compose a report about rocks for inclusion in the class newsletter that was to be shared with the second graders in the school. To help her students take good notes during reading, Mrs. Kaplan had planned to conduct a lesson on two-column note taking (see Chapter 5) the next day.

A sample rock report, composed by Payton's team, follows.

> Rocks have been around for thousands of years. They can be found almost anywhere. There are three kinds of rocks: igneous, sedimentary, and metamorphic.
>
> Igneous rocks are formed by magma. Magma explodes out of a volcano and then hardens up. If it hardens quickly, it will have large crystals. If it hardens slowly, it will have small crystals or no crystals. It will look glassy. Some igneous rocks are obsidian and basalt.
>
> Sedimentary rocks are formed when sediment, sand, soil, and gravel pack together. Fossils are sometimes found in a sedimentary rock. Some sedimentary rocks are granite and limestone.
>
> Metamorphic rocks form when a sedimentary rock, igneous rock, or another metamorphic rock sinks to the core of the Earth and it changes by heat and pressure. Crystals are very common in these rocks. Fossils are sometimes found too. Some metamorphic rocks include gneiss, which comes from granite, and marble, which comes from limestone.
>
> These are the three basic kinds of rocks on Earth.

Figure 1.2 An Inquiry-Based Science Lesson on Acids and Bases

Investigating Acids and Bases

It's Tuesday afternoon in Mr. Bellamy's seventh-grade science classroom, where students were learning about acids and bases. The lesson began with the teacher reviewing the textbook excerpts the class had been reading over the last week. The excerpts were about acid rain and its impact on limestone topography. The review ended with the students raising questions about the chemical nature of other substances such as water, soda, and vinegar and how these substances react with limestone. The questions were written on a piece of chart paper. Through class negotiations, the students decided to explore the acidity and alkalinity of a range of everyday substances.

Mr. Bellamy divided the class into groups of four and gave each group a few substances, such as tap water, distilled water, vinegar, and popular soda drinks (like Pepsi, Coke, Sprite). He then wrote the following questions on the Smart Board: (a) What is the pH of each of these substances? and (b) How is the pH of each substance related to acidity and alkalinity? The students discussed these two questions in their groups, generating hypotheses and brainstorming ideas for testing them. Mr. Bellamy listened in on the conversations, encouraging each group to decide how to proceed toward answering the two questions.

As the students began to conduct their experiments, Mr. Bellamy went from one group to the next, making observations and asking questions. His goal was to ensure that his students worked like scientists—discussing ideas among themselves, documenting their observations, and using data to verify predictions and draw conclusions. He noticed that each group was proceeding at a different pace. One group in the front of the room, for example, was deciding on how best to represent their data. The group members all agreed on using a table but were struggling with an appropriate title for each column in the table. Other groups had begun testing the substances with the universal indicator.

When he moved to the last group of four girls in the back of the room, Mr. Bellamy noticed that they had already tested their substances and recorded the data in a table. The group was using the evidence to arrive at a conclusion. When the girls declared that they were finished, Mr. Bellamy prompted them to compare their conclusion about acids and bases with the information presented in their science textbook. "Now, everyone," he said, "let's reread the section on acids and bases in the textbook and see if the conclusions you have drawn from your experiment are supported in the text. You should also consider reading one of the three books in our classroom library to determine what other activities you might conduct to extend your knowledge about acids and bases." The three books that Mr. Bellamy referred to were *Acids and Bases* by Rebecca Johnson,[33] *Acids and Bases* by Carol Baldwin,[34] and *Acids and Bases* by Chris Oxlade.[35] He had bought them for use with the unit.

When all groups concluded their experiments, Mr. Bellamy held a class discussion to address the two questions he had posed earlier about the pH values of everyday substances and their relationship to acidity and alkalinity. Toward the end of the discussion, Mr. Bellamy prepared his students for next week's topic on "acids in the atmosphere" by asking them to read related trade books in the classroom and school libraries and gather information about the topic on the Internet. The students were to prepare a letter to a local newspaper discussing the impact of acids on the environment and what the government had done to regulate acid emissions from a local chemical plant. To prepare his students for the writing task, Mr. Bellamy had planned a lesson on paraphrasing (see Chapter 4), a strategy for translating the technical, dense language of science texts into a more commonsense type of language that is comprehensible to the newspaper readership.

hypotheses; designing and conducting an experiment; using appropriate tools and techniques to collect, analyze, and interpret data; developing descriptions, explanations, predictions, and models based on evidence; drawing conclusions; communicating results and arguments; and generating additional questions for further inquiries. Both teachers emphasized the development of science knowledge, skills, habits of mind, values, and attitudes by providing opportunities for their students to ask questions, explain problems, design and carry out experiments, engage in reading and writing, interpret information, share ideas, validate conclusions, and communicate understandings.

In Mrs. Kaplan's lesson, the fourth graders developed their conceptual understanding of rocks through not only the firsthand experience of examining real rocks but also the secondhand experience of reading books about rocks and discussing and writing about rocks. The K-W-L chart was used to activate the students' prior knowledge and help them set a purpose for inquiry. During the hands-on experience, the students engaged in collecting data and using the data to make grouping decisions for their rock collections. The home reading assignment allowed the students to gain more in-depth information about rocks, furthering their inquiry into and learning about the topic. The two-column note-taking lesson prepares the students for the writing project. The publication of a class newsletter promotes the use of language to communicate what the students have learned and understood about rocks.

In Mr. Bellamy's lesson, the seventh graders raised a number of questions based on their reading of the science textbook and the ensuing class discussion. One of the questions became the focus of class inquiry. The teacher then provided experiences that fostered deep and robust conceptual understanding by encouraging his students to design experiments, make predictions, collect data, propose explanations, consider alternative explanations, and draw conclusions. He also encouraged his students to connect science with society by having them write a letter to the editor of a local newspaper discussing the environmental impact of acids. The lesson on paraphrasing prepares the students to make appropriate use of language according to the purpose and audience of the writing task.

The approaches used in Mrs. Kaplan's and Mr. Bellamy's classes are different from how science has traditionally been taught. In most classrooms, teachers are viewed as experts who provide carefully outlined procedures for the completion of assigned science activities. Usually these activities lead to one "correct" answer, often believed to be located in the textbook. What is required is the development of specialized skills, such as the ability to follow instructions and manage activities within a given timeframe. In many instances, these skills are developed out of context and are unrelated to the activities that investigate and analyze science questions. In short, traditional science teaching reinforces the myth of science as a body of information or facts created by experts for students to memorize. The inquiry-based approach illustrated in the two sample lessons, on the contrary, portrays science as a process for understanding the natural world and as a way of thinking and reasoning. It also allows for the use of diverse methods to develop and renovate knowledge in science.

LANGUAGE AND LITERACY IN INQUIRY-BASED SCIENCE

In Mrs. Kaplan's and Mr. Bellamy's lessons, reading and writing are an integral part of inquiry, as students use texts (textbooks, trade books, websites, and so on) to generate questions, access information, validate conclusions, communicate knowledge and understanding, and stimulate further inquiry. The two lessons exemplify a second strand of the current science education reform, which is to encourage interaction between the literacy and the science education communities.[36] This reform initiative recognizes that science is a process of inquiry conducted through the use of language. On one hand, science is an organized human activity that seeks knowledge about the natural world in a systematic way. It requires the use of scientific methods for observing, identifying, describing, and experimentally investigating the natural phenomenon. On the other hand, science is also a form of discourse involving the use of language, particularly written language. Scientists use language in conducting scientific inquiries and in constructing theoretical explanations about the natural phenomenon. They also use language to communicate scientific knowledge, principles, procedures, and arguments to others. This means that to be truly literate in science, students must be able to both conduct scientific inquiries and read and write science texts. Canadian science educators Stephen Norris and Linda Phillips captured this duality of science literacy by indicating that students need not only to be knowledgeable about the substantive content of science (that is, the derived sense of science literacy) but also fluent in the language and discourse patterns of science (that is, the fundamental sense of science literacy).[37]

This renewed emphasis on the role of language and literacy within science education is warranted on several grounds. First, language was and still is the principal resource for making meaning in science.[38] It enables scientists to construct, organize, communicate, interpret, and challenge scientific knowledge, claims, and arguments. According to Norris and Phillips, the development of modern Western science is dependent on written language and reading and writing are "inextricably linked to the very nature and fabric of science."[39] This means that the ability to read and write science texts is no longer an optional extra in science education. It is, in the words of British science educators Jerry Wellington and Jonathan Osborne, "an absolute essential for the development of scientific literacy."[40] Without the ability to read and write science texts, students are severely handicapped in their inquiry endeavor and limited in the depth and breadth of scientific knowledge and skills they can attain.

> *The ability to read and write science texts is no longer an optional extra in science education.*

Second, reading and writing are powerful vehicles for engaging students' minds, for fostering the construction of conceptual understanding, and for supporting inquiry and problem solving in science.[41] Reading and writing involve many of the same cognitive skills and processes that are central to inquiry science, including predicting, inferring, monitoring, making connections, analyzing, verifying, drawing conclusions, problem solving, interpreting, and critiquing. They provide an opportunity for students to engage in secondhand investigations that reinforce, extend, and enhance the firsthand experience of experiments and observations.[42]

Third, reading and writing constitute an integral part of the social practices that scientists engage in. Real scientists read and write articles in their fields with care and critical-mindedness.[43] They read to evaluate the information and arguments presented in the text and make judgments about the trustworthiness of knowledge claims. They also write to reflect on their thoughts and ideas, to offer alternative explanations of the science phenomenon or issue at hand, and to document proprietorship of intellectual properties.[44]

Fourth, it has been demonstrated that school science texts are simultaneously dense, technical, abstract, and complex.[45] These texts are different from the more familiar and "friendly" storybook texts that students are used to reading and writing in the primary years of schooling (Grades K–2). Students need new language skills and literacy strategies to handle the more demanding reading materials that are required of them beyond the primary grades. However, many preadolescents and adolescents lack such skills and strategies. They often have misconceptions about science reading, science text, and science reading strategies.[46] Recent evidence suggests that a staggering number of students in Grades 4 through 8 are not able to read and comprehend content-area texts in school subjects such as science. According to the 2005 NAEP reading assessment, for example, 38% of fourth graders and 29% of eighth graders are reading below the Basic level, meaning that they are not able to demonstrate an overall understanding of what they read; less than one-third of fourth and eighth graders read at or above the Proficiency level, a level that is considered essential for academic success.[47] This situation necessitates a continuing emphasis on language and literacy beyond the primary grades so as to ensure that students develop new skills and strategies for successfully interacting with content-area texts.

A staggering number of students in Grades 4 through 8 are not able to read and comprehend content area texts.

Fifth, empirical research has provided substantial evidence that suggests integrating language and literacy practices with science can significantly improve students' engagement with and learning of science.[48] These studies demonstrated that by providing students time to read and write science and by teaching them how to use a repertoire of reading and writing strategies, teachers could not only enhance students' capacity to comprehend and compose science texts (that is, the fundamental sense of science literacy) but also their science knowledge, habits of mind, and inquiry skills (the derived sense of science literacy).

In short, the current push to make language and literacy a legitimate part of science education has both theoretical and empirical support. It has heightened the awareness within the science education community of the role language and literacy plays in informing science teaching and in empowering science learning. Increasingly, there are calls for science teachers to embed language and literacy practices in authentic science inquiry "so that all students have a greater chance of fully achieving science literacy."[49]

OVERVIEW OF THIS BOOK

This book responds to the recent call for science teachers to use documented language and literacy practices in support of science teaching and learning. It describes ways to integrate language analysis, reading and writing strategy instruction, and quality trade books into inquiry-based science classrooms, helping science teachers more effectively promote science literacy development for all students.

The book is intended for science teachers in Grades 3 through 8. It is also suitable for reading teachers, literacy coaches, and those who are interested in infusing language and literacy practices into content-area instruction. The book can be used in professional development workshops, institutes, and study groups. It is also appropriate for science methods and reading methods courses, as well as for topical seminars in science or literacy education.

The book consists of six chapters. Chapter 1 (this chapter) discusses and illustrates the notion of inquiry-based science as defined by the science education community and presents a rationale for integrating language and literacy practices into the science curriculum. Chapter 2 discusses what it takes to comprehend a text and identifies the key grammatical features of science texts and the challenges these features present to reading comprehension. Chapter 3 explains the rationale for infusing trade books in the science curriculum, describes key resources for finding quality science trade books, identifies several additional skills needed in reading science trade books (beyond those discussed in Chapter 2), and describes the many ways trade books can be used to empower science learning. Chapter 4 presents a variety of discipline-specific language-based strategies for helping students cope with the often technical, dense, abstract, and complex texts of science. Chapter 5 describes the "what" and "how" of nine reading strategies for scaffolding students' interaction with science texts before, during, and after reading. Chapter 6 presents information on how to help students learn to write basic school-based science genres and to use writing as a tool for learning science. Taken together, the entire volume provides a wealth of evidence-based strategies, practical ideas, and valuable resources for infusing language and literacy practices into inquiry-based science classrooms.