Inquiring into Inquiry Learning and Teaching in Science

Edited by

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American Association for the Advancement of Science
Washington, DC

This publication was supported by the American Association
for the Advancement of Science. Any interpretations and conclusions
are those of the authors and do not necessarily represent the views
of the American Association for the Advancement of Science.

ISBN 0-87168-641-4
AAAS Publication 00-1S

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Introduction

Jim Minstrell and Emily H. van Zee

"Teachers of science plan an inquiry-based science program for their students," according to Teaching Standard A recommended by the National Research Council (NRC) in the *National Science Education Standards* (1996) (p. 30). In planning this inquiry about inquiry learning and teaching, we chose to focus on three questions: Why inquiry?, What does inquiry look like?, and What are some of the issues associated with shifting toward inquiry-based practices? In inviting authors to contribute, we tried to include many perspectives—from scientists, teachers, researchers, professional development specialists, and administrators. We particularly tried to include authors who are working with students from diverse cultural backgrounds and socioeconomic circumstances. Settings ranged from science lessons with primary students to informal meetings with experienced teachers. We asked authors to define what they mean by inquiry teaching and learning and then to address a relevant question or issue in the context of their own practices. We invite the reader to join us in pondering these responses.

WHY INQUIRY?

In the first section of the book, leaders of the science and science education communities reflect upon what they mean by inquiry and why they think inquiry should be emphasized in school science. These chapters also provide historical and philosophical perspectives on the current reform efforts.

How do scientists think about inquiry? Bruce Alberts, president of the National Academy of Sciences, reflects upon meaningful aspects of his early education and notes that these were associated with "struggling to meet a challenge in which my own initiative was needed to acquire an understanding." He provides some examples from inquiry curricula and also some counterexamples, including college science labs that he found "utterly boring." Alberts includes a delightful passage from Richard Feynman's account of a conversation Feynman had as a child with his father. Alberts uses this to illustrate ways to develop a student's inquisitiveness; he then challenges college faculty to develop courses that nurture such habits of mind. He suggests that scientists have a responsibility to volunteer in schools, provide professional development for teachers, and form a political force advocating reform. He also encourages young scientists to consider teaching at the K-12 level as a way of reinvigorating the schools.

How do teachers think about inquiry? Gerald F. Wheeler, Executive Director of the National Science Teachers Association, comments on three faces of inquiry. Some teachers seem to view inquiry simply as a teaching strategy for motivating students by engaging them in hands-on activities. This is not enough. Students need to learn how to question the phenomena, that is, to engage in a dialogue with the material world. Wheeler's teaching goal is to place students in situations that enable them to practice having such dialogues. Also important is to see the structure of inquiry itself as a content to be learned. Students need to become aware of the nature of scientific ways of knowing. As they design and conduct investigations, they should recognize the need to identify assumptions, to use critical and logical thinking, to base inference on evidence, and to consider alternative explanations.

What is the history of inquiry approaches to science instruction? An overview is provided by Rodger W. Bybee, former Executive Director of the Center for Science, Mathematics, and Engineering Education at the National Research Council, who now directs the Biological Sciences Curriculum Study. Bybee begins by presenting three versions of inquiry in action and presenting the reader with a quiz to assess interpretations. Then he traces the history of inquiry teaching from late in the nineteenth century to the present, including views expressed by John Dewey, Joseph Schwab, F. James Rutherford, and agencies such as the American Association for the Advancement of Science, as presented in Project 2061's publications, and the National Academy of Sciences in the *National Science Education Standards* (NRC, 1996). Bybee distinguishes between two ways in which the *Standards* use the term "inquiry": to refer to content and to teaching strategies. The content standards include understanding fundamental abilities and concepts associated with science as inquiry. Bybee recommends starting with a standards-based perspective, What is it we want students to learn? and then asking Which teaching strategies provide the best opportunities to accomplish that outcome? and What assessment strategies are appropriate and provide the best evidence of students' attaining the outcomes?

What philosophical bases underlie a conception of science as inquiry? Fred N. Finley, a professor of science education, and M. Cecilia Pocoví, a scientist from Argentina, review how the scientific method is typically presented in science textbooks and why teachers might choose this traditional view of scientific inquiry. They reflect upon successes associated with the development of the scientific method and its relation to the development of intellectual freedom, new forms of government, and technological advances. Then these authors reconsider each element of the traditional scientific method taught in schools in the context of issues raised by recent philosophical debates about the nature of scientific inquiry. They recommend, for example, that students learn about the effect that preconceptions and theories of the world have upon questions formulated, observations made, and interpretations developed. Students should learn that scientific inquiry does not always involve experimentation, that there are many contexts in which other approaches are more appropriate. Students also should become aware of the importance of the discussions, arguments, and modifications typical of the presentation of new ideas in a scientific community.

WHAT DOES INQUIRY LOOK LIKE?

This section presents examples of inquiry teaching and learning in several contexts. These include elementary and secondary classrooms, professional development programs in a variety of settings, and college science courses for teachers. Each chapter contributes specific instances and insights to our general inquiry about inquiry learning and teaching.

How might elementary school teachers shift toward more inquiry-based practices? Teachers who have been primarily using textbooks might engage students in more hands-on activities. The *National Science Education Standards* (NRC, 1996) notes, however, that providing more experiences with natural phenomena is not enough: students also need opportunities to talk together about what they think. Especially important are opportunities to formulate theories and to consider evidence that confirms or disconfirms these ideas. A university researcher, Sandra K. Abell, and two third-grade teachers, Gail Anderson and Janice Chezem, provide examples of shifts in practice toward greater emphasis on science as argument and explanation. They reflect upon what they learned about inquiry teaching and learning as they engaged students in thinking together about whether sounds are produced by vibrating objects.

How can teachers design classrooms to support inquiry? A team of university researchers, Richard Lehrer, Susan Carpenter, and Leona Schauble, and a first-grade teacher, Angie Putz, present a vision of inquiry teaching and learning that demonstrates ways to encourage and shape student questioning. They trace the chain of inquiry during a year-long investigation initiated by the children's curiosity about changes in the color of apples. The children designed strategies for testing their ideas about ripening, invented ways to record their observations, extended their investigation to decomposing, compared rates of change for several kinds of fruits and vegetables, and constructed models of phenomena they had decided to track. The teacher's design tools included asking questions that pushed students' questions farther, establishing norms of argumentation based on evidence, focusing upon displays and inscriptions invented by students, and engaging students in evolving chains of inquiry.

How can college faculty foster teachers' inquiries about inquiry learning and teaching? Emily H.van Zee reviews some of the literature generated by teachers reflecting upon their own practices, particularly those who are documenting and articulating ways in which they teach science through inquiry. Then she describes ways that she engages prospective teachers in learning how to do research as they learn how to teach in courses on methods of teaching science in elementary schools. She also discusses the formation and structure of the Science Inquiry Group, teachers who are developing case studies of their own teaching practices. Deborah L. Roberts, a graduate of the course and founding member of the Science Inquiry Group, reflects upon the road she traveled as a teacher who first learned, and now teaches, science through the process of inquiry.

What do teachers inquire about teaching and learning science as inquiry? In the set of case studies included here, teachers formulated issues to examine, collected data such as videotapes of instruction and copies of their students' work, and developed interpretations of their own teaching practices. Many of these teachers are working with students from diverse cultures. Marletta Iwasyk reflects upon ways in which she helped her primary students learn how to ask productive questions of one another. Akiko Kurose presents questions that her first graders asked in a context in which they had had extensive observational experience. Rebecca Kwan comments upon ways in which she modified her curriculum in order to follow up on a first grader's unexpected question. Constance Nissley describes a regularly scheduled Choice Time in which elementary students could follow their own curiosities. Judy Wild reflects upon the development of her fourth graders' conceptual understanding of electric circuits. Diantha Lay reports upon an inquiry conference that she organized for her fourth graders to share their science projects with students from other schools. Rhonda Hawkins recounts ways in which three sixth graders were competent science inquirers even though they were not able to communicate their understandings through writing. Dorothy Simpson identifies strategies to foster collaborative conversations among high school physics students.

How can teachers use the results of research on inquiry teaching and learning? Educational research traditionally has provided the basis for design of new instructional methods and materials that teachers then implement in their classrooms. David Hammer, a professor of physics education, describes a different use of research that evolved in a series of meetings with high school physics teachers. He and the teachers discussed snippets that the teachers had selected from tapes of their instruction, samples of students' work, and so forth. They also read reports of research on learning and tried to use insights from these in interpreting the data under discussion. In this way, perspectives from educational research enriched the perceptions and judgments of the teachers as they developed their interpretations. Conversations about the snippets and summaries of teacher perceptions provide models for both teachers and researchers of ways to engage in insightful discussions of theory and practice.

What principles guide the practice of inquiry in informal learning environments? Doris Ash and Christine Klein, museum science educators, describe and compare two museum settings. One is an Institute for Inquiry in which teachers learn science through long-term inquiry activities based upon their own questions. The other is a "museum" school where middle school students do research in the authentic context of enriching the exhibits. The authors compare learning in informal and formal environments, present vignettes from their two settings, define common principles, suggest ways of implementing these principles in other contexts, and include resources for putting these principles into practice. They emphasize two elements in building a community of inquiry: an ethos of questioning and scaffolding. According to these authors, learning is a social process driven by the learners' curiosity. In facilitating inquiry, knowing when and how to intervene is critical.

How can college science faculty prepare teachers to develop an inquiry-based science program? College faculty provide implicit models of science teaching by the ways that they structure their courses. If teachers are to teach science by inquiry, they need to have experiences learning science by inquiry in the college courses required for their majors. A university professor and an elementary school teacher provide two perspectives on the need for special science courses for teachers. Lillian C. McDermott, a professor of physics, discusses why traditional college science courses are inadequate for preparing teachers to teach science at any level—elementary, middle, or senior high school. She then describes the intellectual objectives and instructional approach of special physics courses for teachers. These courses served as the setting for development of a curriculum for college courses for teachers, *Physics by Inquiry* (McDermott, 1996). Taught entirely in the laboratory, these courses develop not only knowledge of subject matter but also knowledge of difficulties that students may encounter in learning these topics. Lezlie S. DeWater reflects upon what she experienced initially as a participant and then as a staff member in these courses. In particular, she discusses how she questions and listens to her students as she guides them in making sense of the world around them.

What strategies can college professors use to implement inquiry-based instruction? Kathleen M. Fisher, a professor of biology, reviews reasons for modeling such teaching, comments on when to avoid inquiry approaches, describes several inquiry-based strategies, and summarizes ways that she has adapted a lecture course for active learning. She also discusses six features of inquiry-based learning: eliciting prior knowledge, prediction, engagement with a phenomenon, group work, higher order thinking, and student-centered classes. Then she describes

SemNet®, a computer program that students can use to create a map of ideas having many complex interconnections. She closes the chapter by reviewing some of the evidence for the need for change in the ways we teach and learn.

WHAT ISSUES ARISE WITH INQUIRY LEARNING AND TEACHING?

This section examines some of the issues that teachers may consider in shifting toward inquiry-based instruction. These include using technology to support inquiry, incorporating metacognitive strategies, attempting inquiry with young children, addressing students' reasoning difficulties, teaching students with disabilities, clarifying instructional goals, and assessing learning.

In what ways can technology support students' inquiries? University researchers, Joseph Krajcik, Phyllis Blumenfeld, Ron Marx, and Elliot Soloway, describe instructional, curricular, and technological supports for inquiry in science classrooms. They provide examples of ways that learning technologies can enhance the formulation of questions, design of investigations, collection and display of data, development of analyses, and presentation of findings. The Investigators' Workshop, for example, includes computational tools such as Model-It that help students to build, test, and evaluate models of dynamic systems. These authors emphasize the roles of metacognition and collaboration in inquiry. Karen Amati is a science and technology resource teacher who provides a detailed account of using Model-It with urban middle school students. She describes how Model-It prompts students to develop explanations rather than memorize definitions or bits of information. She also comments upon the role of the teacher as a facilitator of learning.

Can students learn to assess their own reasoning as they construct and revise theories? Researchers, Barbara Y. White and John R. Frederiksen, collaborated with teachers in developing and testing a computer-enhanced science curriculum in urban middle schools. The ThinkerTools Inquiry Curriculum enables students to learn about the processes of scientific inquiry and modeling as they construct and revise theories about force and motion. Students evaluate their own and one another's research in a reflective process that includes assessing whether they are reasoning carefully and collaborating well. This process is called "metacognitive facilitation." The ThinkerTools curriculum was effective in reducing the performance gap between low and high achieving students.

Is inquiry-based instruction appropriate for young children? Kathleen E. Metz, a professor of education, challenges the traditional assumption that young children are not developmentally ready to engage in abstract thinking.

She suggests that the ability to reason competently depends upon the depth of children's knowledge. Such knowledge includes not only conceptual understanding of the domain but also knowledge of the enterprise of empirical inquiry, of methodologies specific to a domain, of ways to represent and analyze data, and of the use of tools such as binoculars, thermometers, and computers. This author then describes a project to help young children build knowledge that will empower their independent inquiry in biology. She provides examples of a curriculum module in animal behavior, children's reflections upon their inquiries, and teachers' perspectives on the value and challenges of this approach.

How can teachers address students' reasoning difficulties? Anat Zohar, a professor of science education, considers various challenges that students encounter such as matching research problems to appropriate experimental designs, controlling variables, applying the logic of hypothesis testing, and differentiating between experimental results and conclusions. She advocates teaching such reasoning skills systematically and provides an example from the Thinking in Science project. This curriculum explicitly teaches scientific reasoning in subjects that are part of the regular science syllabus. Activities include investigation of microworlds, learning activities promoting argumentation skills about bio-ethical dilemmas in genetics, and open-ended inquiries. The curriculum builds upon examples with which children are familiar from everyday life, provides opportunities to practice reasoning skills in several contexts, and engages students in metacognitive activities that lead to generalizations about reasoning formulated by the students themselves.

Can students with disabilities learn science as inquiry? Professor of science education, J. Randy McGinnis, reviews the literature in four areas: portrayals of inquiry learning by instructors teaching science to students with disabilities, reasons for using inquiry-based instruction for students with disabilities, evidence that such instruction is appropriate for these students, and implications for teachers. The latter include developing inquiry-based instruction while establishing differing expectations for student assessment based upon the objectives in the students' Individualized Education Plan. Close collaboration with special educators is advisable. Also recommended were providing structure through use of a student notebook with a format, introduction of key vocabulary and material by the teacher, student generation of predictions or hypothesis on what will be learned from an experiment, participation in experimental activities, oral presentations by the learning groups on the data they collected, elicitation of summary statements, and group construction of conclusions.

What is the purpose of "practical work" in school science? Brian E. Woolnough, a science educator from Great Britain, asserts that much practical work is "ineffective, unscientific...boring...time wasting…and unstimulating" because students do the experiments by following step-by-step procedures to verify known principles with little intellectual curiosity, purpose, or motivation. Woolnough distinguishes between acquiring scientific knowledge through prescribed laboratories and learning to do science. He advocates engaging students in authentic science activities of a problem-solving investigative nature that develops their expertise in working like scientists. The CREST program (CREativity in Science and Technology) provides an example of a program that has stimulated many students to become involved in genuine scientific and technological activities. The outcomes of such student projects include motivation, challenge, ownership, success, and self-confidence as well as acquisition of scientific knowledge and skills.

How can inquiry learning be assessed? University researchers, Audrey B. Champagne, Vicky L. Kouba, and Marlene Hurley, reflect upon the complexity of assessment at all levels. They distinguish between scientific inquiry as practiced by scientists and science-related inquiries as practiced by science literate adults and K-12 students. Science-related inquiries include information-based investigations to assist in decision making and to evaluate claims as well as experimentation to test theories and laboratory-based investigations. Champagne, Kouba, and Hurley delineate projects, abilities, and information assessed during four phases of laboratory investigations: when questions are generated, an investigation is planned, data are collected and interpreted, and conclusions argued and reported. In addition, they discuss decisions, assessment strategies, and individuals responsible for assessments that inform classroom practices and report student progress. The authors provide a similar matrix for planning and evaluation of K-12 programs and courses.

WHAT HAVE WE LEARNED ABOUT INQUIRY?

In the epilogue, Jim Minstrell reflects upon what we have learned about inquiry through the process of reading and talking and thinking with the authors and each other. He identifies some common themes embedded in the chapters of this book but points out that inquiry is complex. It likely involves integrating several of these themes into a coherent view of teaching and learning that closely approximates the activities of scientists as they attempt to make sense of their experiences. To summarize and make these themes more real, Minstrell uses a vignette to discuss them in the context of his own teaching practices.

What is inquiry? We knew when we started this project that we were unlikely to come to a definitive answer. What we have gained, however, is a much deeper appreciation of its complexity. We invite you and your colleagues to join us in this inquiry about inquiry learning and teaching in science.

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