SCIENCE INSTRUCTION
IN THE MIDDLE AND SECONDARY SCHOOLS

FOURTH EDITION

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Frank Darrow

To the science educators who made significant contributions to this text through their research, scholarship, and suggestions and to the members of the science teaching profession who are graduates of our respective science education programs

PREFACE

Science Instruction in the Middle and Secondary Schools is intended to help science teachers prepare students to become scientifically and technologically literate in order for them to lead a productive life in a sophisticated biotechnological, electronic, and communication era. This goal presents a tremendous challenge for science teachers because of the fundamental understanding that students must acquire concerning science, mathematics, and technology, and because of the dynamic nature of the American society with its cultural diversity and ongoing social changes. In addition, there are too many students reporting that science courses are difficult and uninteresting. It is also the case that some segments of our society are not only underrepresented in science and engineering professions but are receiving a less than adequate science education.

In response to the present situation in science education, a national science education reform movement is underway in America. Two foci of the reform emphasize that science is for all students and that learning science is an active process. Another focus is the teacher. We believe that science teachers must consider many facets of science teaching in order to provide science courses that meet students' needs and help them to appreciate science and technology. Teachers must understand the nature of science and technology and possess a strong content background. They must also understand how students learn and be able to ascertain what knowledge and skills students possess when they enter the classroom. Teachers must be able to use a variety of instructional strategies to help students represent knowledge and find meaning in it. Furthermore, science teachers must be able to develop alternative and authentic assessment programs that address many learning outcomes in order to determine student achievement. Finally, science teachers should become active in local, state, and national professional organizations so that they continue to stay up-to-date and grow professionally.

New features have been added to the fourth edition. Open cases can be found near the beginning of many chapters. "Stop and Reflect" exercises have been placed at the end of certain sections within each chapter. "Resources to Examine" are at the end of each chapter. Little science puzzlers, science demonstrations, and science laboratory activities can be found in the appendixes. These features are described below.

Use of This Text

Those who use this methods textbook should use it interactively. Exactly how it will be used must be in accord with the instructor's own background and expertise in science and science teaching. In some instances the book may be used to introduce concepts or ideas that are later expanded upon through class discussion, teacher demonstration, or laboratory activities. Here the book serves as the students' first contact with understandings critical to their success as future teachers. At other times the book may be used to provide students with additional information regarding an important idea or teaching practice after it is introduced in class. Here the book functions to reinforce and strengthen the understandings introduced by the instructor. By no means should this book be viewed as the sole and definitive source on science teaching and learning.

Features of the Text

Science Instruction in the Middle and Secondary Schools has many unique and useful features. Of particular interest are vignettes and open cases that highlight particular teaching situations. These offer wonderful opportunities for students to critique and reflect on real-life classroom experiences. A feature called "Stop and Reflect" appears frequently in most chapters to help students review and construct meaningful understandings from what they have read. These segments in the textbook will further assist methods course instructors to use the text interactively.

Many activities are described in the text to highlight important teaching methods and aspects of science learning. In addition, many science activities are described in the appendixes for methods course instructors and their students to use. These activities are grouped as science puzzlers (Appendix A), science demonstrations (Appendix B), and science laboratory exercises (Appendix C). At the end of each chapter, an "Assessing and Reviewing" section includes activities and questions that may be used during class or assigned for homework. A section new to this fourth edition called "Resources to Examine" provides information about additional readings, activities, and science teaching materials that we believe all science teachers should have for their professional development.

This methods textbook is the result of more than forty-five years of science education experience. During these years, many changes have occurred in the profession. Nevertheless, other aspects have remained the same. Science teachers who are knowledgeable and enthusiastic about their work and who make science relevant and interesting seem to produce positive results through their teaching. We have tried to emphasize in this textbook what effective science teachers have always displayed in their teaching as well as to incorporate new research findings.

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Eugene L. Chiappetta
Thomas R. Koballa, Jr.
Alfred T. Collette

Brief Contents

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PART ONE

BACKGROUND FOR TEACHING SCIENCE

CHAPTER 1

THE NATURE OF SCIENCE

Science can be thought of as the study of nature in an attempt to understand it and to create knowledge.

Science instruction must reflect valid views of the nature of science. Teachers' lectures, classroom discussions, laboratory activities, assigned readings, long-term investigations, and examination questions should correspond to what are generally accepted as science content and processes. Erroneous beliefs about how scientists go about their work must be eliminated, as must highly simplistic approaches to problem solving and overly simplistic examples of concepts, laws, and principles that distort this scientific knowledge. Science teachers, curriculum developers, and science educators must possess a broad understanding of the nature of science so that they make accurate interpretations and presentations of this discipline. Further, their understanding must lead to helping students appreciate the worth of science and how it can benefit their lives. Science teaching must be in line with relevant and authentic science information in order to improve the scientific literacy of all Americans.

OBJECTIVES

This chapter is designed to help the reader meet the following objectives:

- Arrive at a definition of science that represents what scientists do in their work.
- Reflect upon the extent to which science teaching situations exhibit "authentic science" after examining many facets of the scientific enterprise that are associated with the history and philosophy of science.
- Analyze science teaching situations and instructional materials to determine the extent to which they reflect four dimensions or themes of scientific literacy that are central to science teaching.

WHAT IS SCIENCE?

Arriving at a Definition of Science

Science is a broad-based human enterprise that is defined differently depending on the individuals who view it. The layperson might define science as a body of scientific information; the scientist might view it as a set of procedures by which hypotheses are tested; a philosopher might regard science as a way of questioning the truthfulness of what we know. All of these views are valid, but each presents just a partial definition of science; only collectively do they begin to define the comprehensive nature of science. Science is an enterprise that has changed over the centuries. Further, it encompasses many fields, such as physics, chemistry, biology, and the geosciences, which sometimes employ different approaches to the study of reality. Let's examine what scientists attempt to do in their work to assist in arriving at a definition of science.

Science can be thought of as the study of nature in an attempt to understand it and to create new knowledge that provides predictive power and application. This description is implied in the following statement by Edward Teller (1991), an eminent nuclear physicist:

> A scientist has three responsibilities: one is to understand, two is to explain that understanding and three is to apply the results of that understanding. A scientist should have no other limitations. A scientist isn't responsible for that which he has discovered (pp. 1, 15).

The notion that scientists try to **understand, explain,** and **apply** offers science teachers a simple and clear idea of the scientific enterprise. Scientists strive to understand the phenomena that make up our universe—from the pulsating beats of our hearts to the migration of birds to the explosion of stars. Their aim is to describe the internal and external structure of objects, the mechanisms of forces, and the occurrence of events to the point where their descriptions can be used to predict future events with great precision. Scientific understanding goes beyond description to the deeper level of explanation that coalesces many observations, facts, laws, and generalizations into coherent theories that connect ideas with reality, not only specifying what is occurring, but how and why it is occurring.

Scientists **make public** their understanding through carefully prepared papers. Often their manuscripts are presented at professional meetings and published in professional journals. In both instances, and especially the latter, the work is carefully reviewed by colleagues who make critical comments and suggestions, thereby recommending the work for publication or rejection. Published works are open to additional examination by the scientific community where the **logic and reasoning** can be evaluated and procedures and results can be tested by additional observation and experimentation. Further, the work is open to scrutiny by colleagues in order to determine if **ethical principles** have been violated, such as presenting erroneous data or taking credit for discoveries that others have claimed. Scientific ideas must be articulated in a manner that permits other scientists to **confirm** them, to determine their validity, and to translate the knowledge into useful products.

In addition to understanding and explaining phenomena, scientists strive to apply the knowledge that they construct about the world. Many scientists, along with engineers and technologists, spend much of their time designing and producing **useful products** for society. Most of these products hold the potential to improve the quality of life, such as manufactured drugs, genetically engineered hormones, electronic communications, superconducting devices, and the like. It's impossible to calculate the number of ways in which science and engineering have added to our quality of life, but the fact that they have done so has earned them high esteem in our society.

The earlier statement that we quoted by Edward Teller that scientists are not responsible for their work is open to debate, because many would argue that science is a human activity and those involved must be responsible for their actions and products. There is a significant relationship between science and society, in which the society keeps watch over and influences the scientific enterprise.

■ STOP AND REFLECT! ■

Before reading further, do the following:

- Answer the question, What is science? Include in your answer what scientists do in their work.
- Use your definition of science to examine the activity "Investigating Animals' Reactions to Light" in Box 1.1 and indicate the extent to which Mr. Pearl's instruction reflects authentic science.

Many Facets of Science

There is more to science than the definition of science and the activities of scientists presented so far. Science encompasses many diverse ideas and has evolved over many thousands of years. Further, various aspects of science are viewed differently by scientists, philosophers,

BOX 1.1

INVESTIGATING ANIMALS' RESPONSES TO LIGHT

Mr. Pearl initiated the study of ecology with a set of investigations concerning animals' responses to light. The inquiry took place over several weeks and paralleled many other instructional activities on the topic. The following is an overview of how Mr. Pearl directed this activity. He began by introducing the project and outlining the procedures to be followed.

MR. PEARL: Over the next three weeks I want the class to study the responses of various animals to light. You will begin by working independently and then with your laboratory group. To start, I want you to do the following:

- Make a list of five to ten animals and describe how you believe they react to light. Consider when the animals seek food, eat, and sleep. Remember that humans are classified as animals just as insects, birds, and mammals are.
- For each animal, explain its response to light by specifying how the behavior is beneficial to the organism.
- Identify two or three animals that you wish to study because it is possible to either observe them in their natural environment or to maintain them in our classroom/laboratory.

After the students thought and wrote for ten minutes, Mr. Pearl led a discussion regarding the animals they listed and their respective reactions to light. The discussion was lively and brought forth many ideas. The students mentioned the nocturnal behavior of bats, owls, and moths. Some students talked about fishing and how certain fish seem to be more active during various times of the day. Others focused on the habits of ants, termites, and worms. One student mentioned reading about the psychological effects that winter has on some people due to the lack of sunshine.

The students were placed into groups to discuss which animals they might study. Then Mr. Pearl worked with each group to select an animal that was feasible for the group to study. The animals identified for this inquiry were brine shrimp, tadpoles, meal worms, and ants. Most of these organisms could be studied in the biology classroom/laboratory. However, one group indicated that they wanted to use a pond in a wooded area of their neighborhood where tadpoles could be observed.

At this point the teacher provided these additional directions to the students:

1. In your laboratory notebook, name the animal you are studying.
2. Write a paragraph describing how your organism might react to light.
3. List five to eight questions that you will attempt to answer from your investigation. Below are a few questions to consider.
   - How does the intensity of the light affect the animal?
   - Does heat play a role in the response to light?

   I'll stop here because I want *you* to generate the questions. When you have a list of questions, discuss them with your lab partners and together decide on the questions you will attempt to answer. Then show the questions to me so that we can determine their suitability for guiding your inquiry.
4. Design procedures to answer your questions regarding light and animal behavior. On a sheet of paper, list a question and outline the procedure that will provide an answer to it. I will discuss the procedure with you and offer suggestions. After