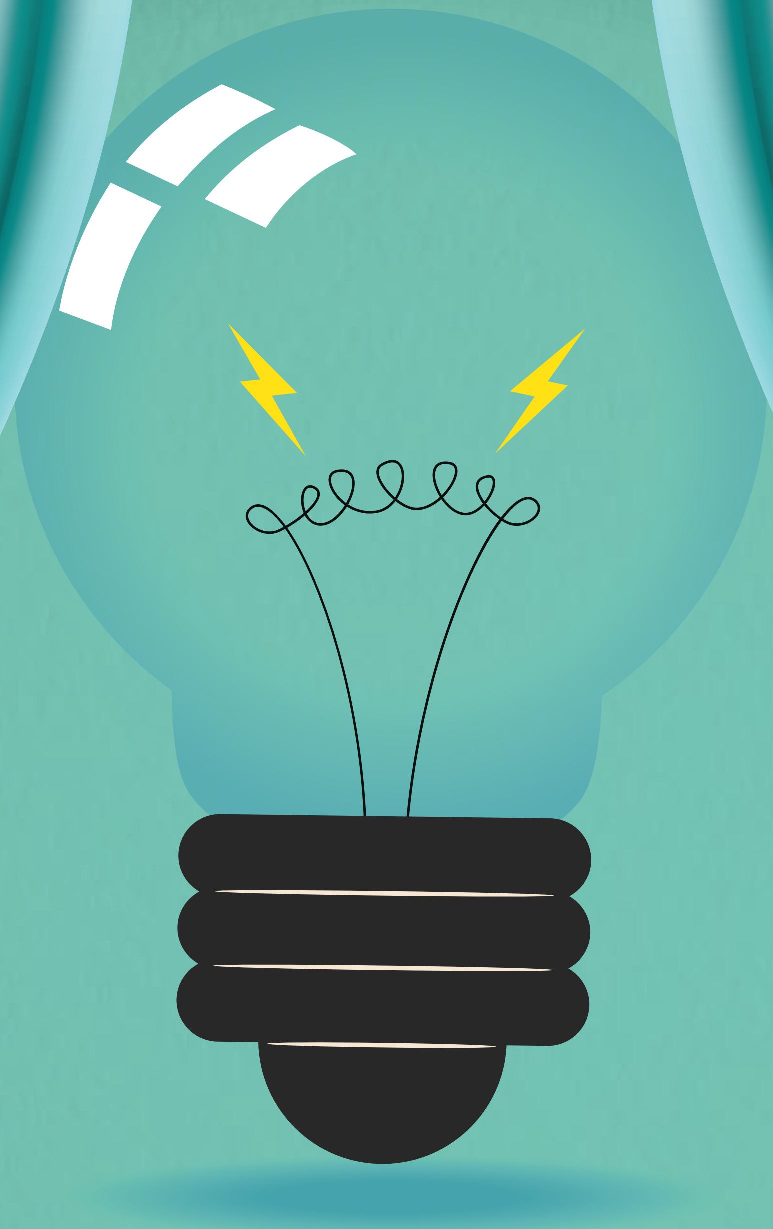


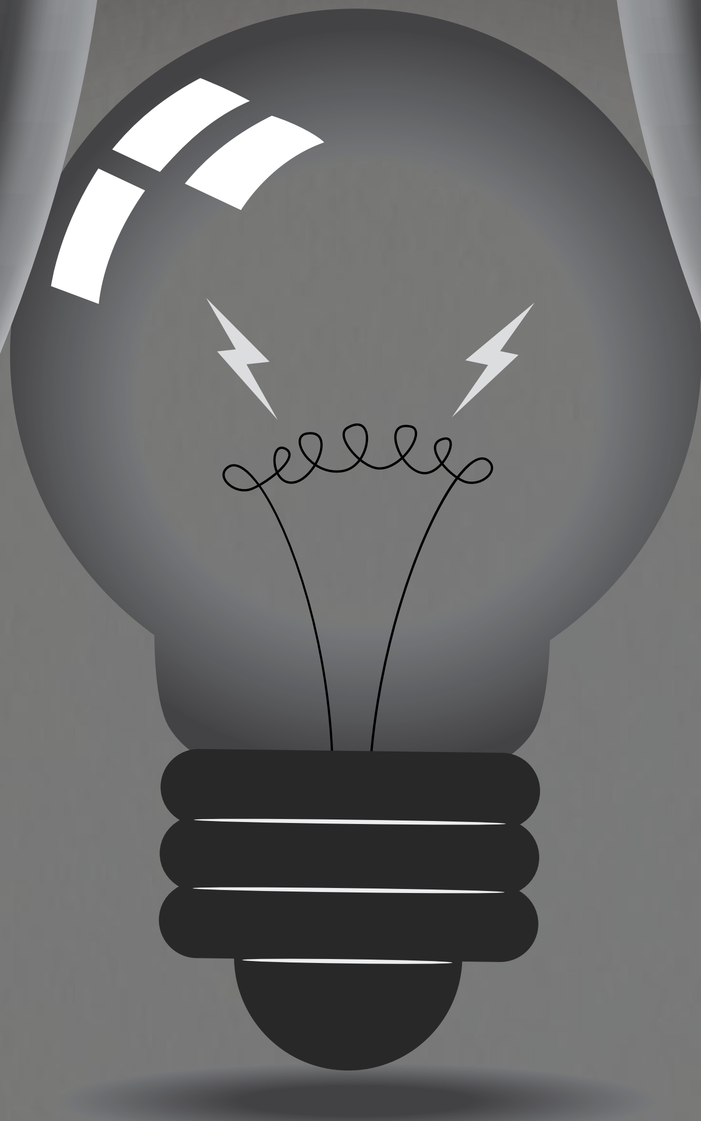
SCIENCE FAIR WARM-UP

» LEARNING THE PRACTICE OF SCIENTISTS «

Teachers Guide

JOHN HAYSOM

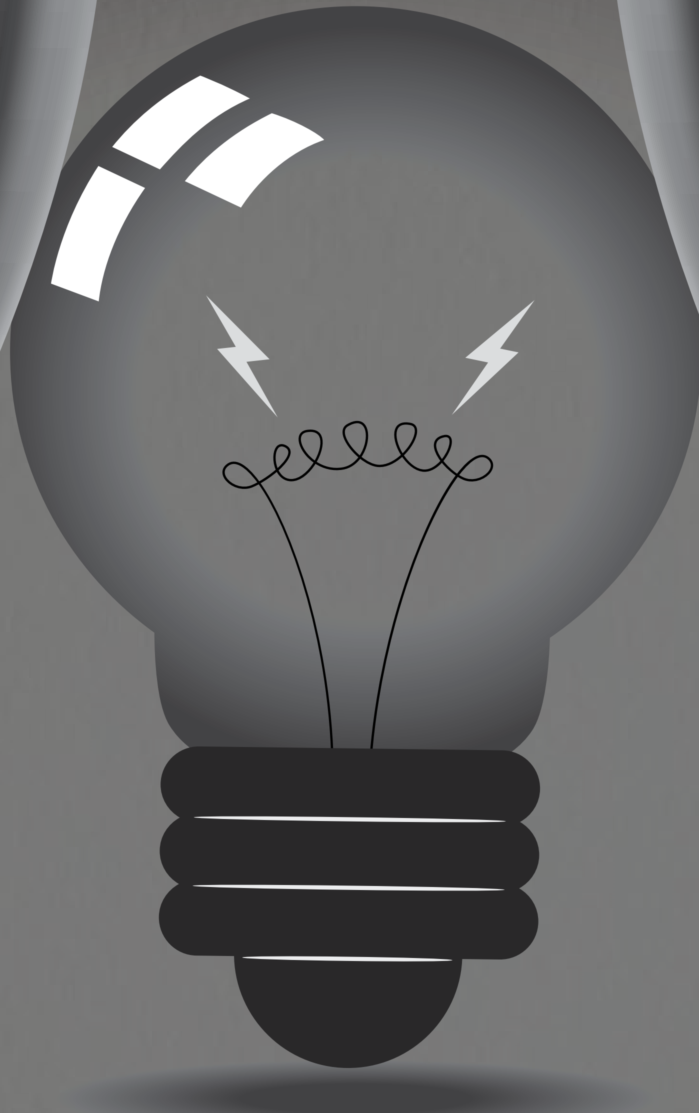
NSTA press
National Science Teachers Association



SCIENCE FAIR WARM-UP

» LEARNING THE PRACTICE OF SCIENTISTS «

Teachers Guide



SCIENCE FAIR WARM-UP

» LEARNING THE PRACTICE OF SCIENTISTS «

Teachers Guide

JOHN HAYSOM

NSTApress
National Science Teachers Association
Arlington, Virginia

NSTA press®
National Science Teachers Association

Claire Reinburg, Director
Jennifer Horak, Managing Editor
Andrew Cooke, Senior Editor
Wendy Rubin, Associate Editor
Agnes Bannigan, Associate Editor
Amy America, Book Acquisitions Coordinator

Art and Design
Will Thomas Jr., Director
Rashad Muhammad, Graphic Designer
Illustrations by Bob Seguin

Printing and Production
Catherine Lorrain, Director
Jack Parker, Electronic Prepress Technician

National Science Teachers Association
Gerald F. Wheeler, Executive Director
David Beacom, Publisher

1840 Wilson Blvd., Arlington, VA 22201
www.nsta.org/store
For customer service inquiries, please call 800-277-5300.

16 15 14 13 4 3 2 1

NSTA is committed to publishing material that promotes the best in inquiry-based science education. However, conditions of actual use may vary, and the safety procedures and practices described in this book are intended to serve only as a guide. Additional precautionary measures may be required. NSTA and the authors do not warrant or represent that the procedures and practices in this book meet any safety code or standard of federal, state, or local regulations. NSTA and the authors disclaim any liability for personal injury or damage to property arising out of or relating to the use of this book, including any of the recommendations, instructions, or materials contained therein.

Cataloging-in-Publication Data is available from the Library of Congress for each student edition.

ISBN 978-1-936959-23-5

eISBN 978-1-936959-68-6

Contents

Contents

Note to Teachers

There are three student books in the *Science Fair Warm-Up* series:

- The book for grades 5–8 includes all the one-star lessons. (See Content Overview, page xxii.)
- The book for grades 7–10 includes the two-star lessons.
- The book for grades 8–12 includes the three-star lessons.

Teachers may wonder which student book or books best meet their needs. Some might be puzzled about how it is possible for a book to be appropriate for such a wide range of grades.

The book for grades 5–8 is particularly suitable for students who have not participated in a science fair before and lays a foundation for the ideas developed in the later books about the practices of scientists. Indeed, even those students who have experienced science fairs before will undoubtedly encounter many ideas about scientific practices that are new to them.

The book for grades 7–10 develops the ideas about practices that students encounter in the first book. Students will also find that the two-star problems are much more cognitively demanding.

The book for grades 8–12 further develops the ideas about the practices of scientists. In addition, many of the problems the students will encounter are challenging, so much so that in field testing the book has been used with both grade 8 students and university science graduates.

It is anticipated that middle school teachers will find the series valuable when they use the first book in grade 6, the second book in grade 7, and the third book in grade 8. In addition, the series provides high school teachers with a curriculum that uniquely meets many of the goals outlined in *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012).

ACKNOWLEDGMENTS

The Story of a Curriculum Project

The stimulus to write this book has come from many people. In the first place, I was motivated by the students themselves. I met many students while judging at science fairs. I was frequently struck by their enormous enthusiasm and pride in what they had done. I also enjoyed the experience of helping my own three children with their projects. I watched their struggles and struggled myself as I tried to assist them—without providing too many solutions to the problems they encountered or taking ownership of the projects from them. The rich educational potential of students undertaking scientific investigations—coupled with an apparent lack of suitable curriculum materials—prompted me to begin this work, which spanned some six or seven years.

I began by asking the students (and their teachers) at Ellenvale School in Dartmouth, Nova Scotia, to share their project work with me. Over the years, I viewed their displays and read hundreds of their reports. This process provided a large bank of interesting ideas for activities and projects and an in-depth appreciation of some of the frequently occurring problems and difficulties students and teachers encountered. I am grateful to the students and teachers for sharing their experiences with me and have included many extracts from their projects.

The curriculum design process that followed was not a linear one, and it evolved slowly. In retrospect, it appears to be somewhat similar to piecing together a three-dimensional jigsaw in which many of the pieces were missing! The first dimension involved relating the problems and difficulties that students met (both at Ellenvale School and elsewhere) to our understanding of how scientists actually work in practice, an understanding that is distinctly different from the common but mistaken view that there is such a thing as a scientific method. The second dimension involved perceiving the problems and difficulties as opportunities for learning and, with this in mind, searching for and devising appropriate learning experiences. Finally, it became evident that some of the learning experiences were more sophisticated than others, either requiring some previous understanding of scientific inquiry or being more intellectually demanding.

The first draft of the materials was used by my student-teachers at Saint Mary's University who were helping teenagers with their project work in a laboratory-school setting. The student-teachers' feedback was frank and formative, and I would like to acknowledge its importance.

I used an expanded second draft of the materials in a local school and was grateful to be able to share my experience with a number of other

Acknowledgments

teachers who had kindly offered to field-test the materials in their classrooms. I would particularly like to acknowledge the continued help I have received from Karen Getson and Bob Dawson at Ellenvale.

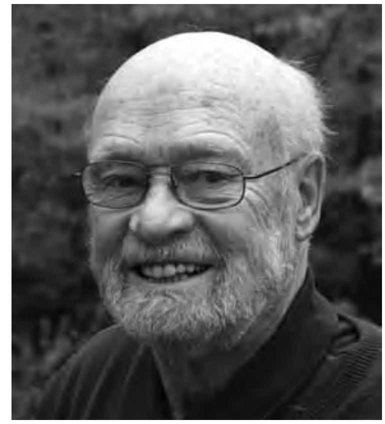
It would not have been possible to field-test the materials at all without the assistance of Sue Conrad at Saint Mary's. She devoted many hours to designing and illustrating the student text. Her influence on its style is apparent.

The final draft was field-tested by still more teachers and was critically but constructively reviewed by Earl Morrison of the Atlantic Science Curriculum (ASCP) Project. Earl and my friends on the Board of ASCP have been a continual source of encouragement. I sincerely appreciate the help that all these people and other colleagues have given me over the years.

In conclusion, I would like to thank Professor Derek Hodson, an authority on the philosophy and sociology of science, for his helpful and insightful comments on the manuscript.

—John Haysom

About the Author



After completing his PhD in chemistry at Cambridge University, John Haysom taught science in a variety of schools before becoming a member of the faculties of education at five universities: Oxford University, Reading University (UK), University of the West Indies, Mount Saint Vincent University (Canada) and Saint Mary's University (Canada), where he is Professor Emeritus.

John has gained an international reputation as a teacher-educator and curriculum developer. In the UK, he was the coordinator of the groundbreaking Science Teacher Education Project, funded by the Nuffield Foundation. This was probably the first teacher education curriculum project in the world and was adapted for use in Australia, Canada, Israel, and other countries. At the University of the West Indies, he was responsible for the design and implementation of an innovative, theme-based inservice B.Ed. curriculum. As professor of education at Saint Mary's University, he initiated and helped lead the Atlantic Science Curriculum Project's SciencePlus textbook series. This curriculum was highly rated and became widely adopted in the United States. He has acted as a science curriculum consultant to the government of Trinidad and Tobago and to a number of projects in the United States.

John is the author of many books for teacher educators, teachers, and schoolchildren, as well as academic papers in curriculum design, evaluation and implementation, and teacher education. His most recent work includes *Predict, Observe, Explain: Activities Enhancing Scientific Understanding* (with Michael Bowen; NSTA 2010) and "Science Curriculum Research and Development in Atlantic Canada: A Retrospective," an article prepared for the *Canadian Journal of Science, Mathematics and Technology Education* (in press).

John has long been interested in science fairs, both as a teacher and a judge, and was elected to the board of directors of the Youth Science Foundation, the national body responsible for science fairs in Canada.

Introduction

Opportunities—wonderful opportunities—are provided in middle schools and high schools across North America for students to participate in science fairs or carry out their own science projects. Although many teachers believe it's valuable for their students to experience genuine scientific inquiry, many teachers also find the challenge a difficult one to meet. Some teachers simply resort to assigning a project for students to complete. Others spend hours doing their best to help more than 100 students individually. Many teachers dread the annual science fair. These curriculum materials are designed to help teachers create courses and programs that address their problems and needs. Two questions loom large in the minds of many teachers:

1. How can you organize 30 students doing 30 different projects at the same time?
2. How can you assist students and, at the same time, provide them with the freedom of choice and independence of thought that characterize genuine inquiry?

These materials address these problems. Because science fair projects frequently involve experimental work, the materials in this book focus on experimental work as well.

It certainly is valuable for students to experience genuine scientific inquiry. The experience provides them with the opportunity to become problem solvers (scientific problem solvers) and gain an understanding of the art of solving problems (the nature of scientific inquiry).

Being a good problem solver is quite different from understanding the problem-solving process. It is one thing to be able to find out for yourself which type of flashlight battery is better and another thing to appreciate or critique the way in which somebody else attacked the problem.

Although these ends are valuable in and of themselves, they also provide a valuable perspective on the way scientists have discovered the truly powerful network of explanations and ideas that enables us to make meaning of our natural world. For many people, it's a mystery where these explanations and ideas came from. For them, the connection between the products of science and people in white coats doing experiments is a tenuous one.

Most of today's science curricula focuses appropriately on helping students understand this network of explanations and ideas, but many students find this a difficult and meaningless task, one devoid of humanity and reality. We might be able to help these students by presenting science as a product of human endeavor. These curriculum materials attempt to do just this and thus might be used to enhance and enrich a curriculum with a product orientation.

Both the *National Science Education Standards* (NRC 1996) and the recently published *A Framework for K–12 Science Education* (NRC 2012) acknowledge these important goals. The Standards has this to say:

> The standards on inquiry highlight the ability to conduct inquiry and develop understanding about scientific inquiry. Students at 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 relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. (NRC 1996, p. 105)

A Framework for K–12 Science Education (NRC 2012) is a remarkable document. It is divided into three major sections: practices, crosscutting concepts, and core ideas. The word *practices* is closely related to ways in which the phrase *scientific inquiry* is used in this book. Incidentally, teachers who wish to deepen their understanding of the nature of science and its importance for science education will undoubtedly find the Framework (and some of the references it contains) most illuminating. Here are a few extracts from the beginning of the section that discuss what is meant by *practices*.

> Understanding How Scientists Work. The idea of science as a set of practices has emerged from the work of historians, philosophers, psychologists, and sociologists over the past 60 years. This work illuminates how science is actually done … (NRC 2012, p. 43)

> Our view is that this perspective is an improvement over previous approaches in several ways. First, it minimizes the tendency to reduce scientific practice to a single set of procedures, such as identifying and controlling variables, classifying entities, and identifying sources of error. This tendency overemphasizes experimental investigation at the expense of other practices, such as modeling, critique, and communication. (NRC 2012, p. 43)

> Second, a focus on practices (in the plural) avoids the mistaken impression that there is one distinctive approach common to all science—a single "scientific" method … (NRC 2012, p. 44)

> Third, attempts to develop the idea that science should be taught through a process of inquiry have been hampered by a lack of a commonly accepted definition of its constituent elements. (NRC 2012, p. 44)

These curriculum materials share these views and are in harmony with the above perspective. Indeed, the materials' design was driven in part by the apparent lack of materials that present an authentic view of the nature of science and scientific inquiry.

The situation in Canada is similar. The Council of Ministers of Education's vision of scientific literacy is built on four foundations, the second of which is skills (CMEC 1997):

> Skills—Students will develop the skills required for scientific and technological inquiry, for solving problems, for communicating scientific ideas and results, for working collaboratively, and for making informed decisions.

These skills are grouped into four main areas: initiating and planning, performing and recording, analyzing and interpreting, and communication and teamwork. The scope and complexity of these skills are developed in grades K–12.

The sections that follow include a discussion of the views taken on the nature of science and scientific inquiry, the teaching strategy used, a consideration of the problem of helping the students develop their independence, an outline of the ways in which the materials have been structured, and an overview of the content.

Nature of Science and Scientific Inquiry

Every set of science curriculum materials inevitably takes a position on the nature of science and scientific inquiry. Indeed, the shape of science curriculum materials is significantly shaped by the designer's views of the nature of science and scientific inquiry. Seldom, however, do you find these views made explicit in teachers guides. At first sight, this may seem rather strange, but it is not an easy task for designers to make explicit their views, and moreover, it is contentious because of the divergence that exists.

In the five paragraphs that follow, I attempt to outline the position adopted in these materials.

a. Scientific inquiry is artful and intuitive.

Some curriculum materials present scientific inquiry as a linear process, one that follows a sequence such as observation, formulation of hypothesis, experiment design, collection of results, and development of conclusions. But do scientists actually proceed this way? How would scientists proceed to investigate bouncing balls? It's likely that many thoughts would go through their heads: "The substance the ball is made of and the substance it strikes might make a difference. How can the height of bounce be accurately measured? What is known about elasticity already?" Why is it that there is a limit to how high a ball bounces regardless of the height from which it is dropped? Sometimes an experiment doesn't work out well. Sometimes a chance observation opens up new avenues of exploration. Scientific inquiry appears to be a messy business; good scientists are guided intuitively as to what to do next. Nobel Laureate Peter Medawar considered scientific reasoning to be a constant interplay of interaction between hypothesis and the logical expectations they give rise to, a restless to and fro motion of thought, a kind of dialogue between the possible and the actual (Medawar 1969). It is just as appropriate to start at the end as it is at the beginning, and although the materials are arranged in a fairly traditional sequence (e.g., from experiment to interpretation of data to explanation), this is not designed to be prescriptive.

The popular idea of the scientific method seriously distorts reality. It portrays the process of discovery as an algorithm that, if simply plugged into a problem, will inevitably unlock our entry to the secrets of the universe.

b. The thinking processes involved in scientific inquiry are interwoven.

Some curriculum materials emphasize the learning of science process skills (observing, classifying, predicting, measuring, inferring, and so on) and proceed to teach these independently of context. But what is the point of observing a candle, classifying buttons, or measuring the width of a table? Developing such skills is important, but they should be learned in context. Learning should be holistic. To do otherwise not only makes learning less meaningful for the students but also gives them a false impression of the nature of science and scientific inquiry.

In these curriculum materials, such skills are developed in context. Bean seed germination is observed with a view to understanding what might speed it up or slow it down, and measurements of magnetic strength are made with a view to finding out the best way to determine the strength of homemade magnets. Different lessons highlight different aspects of the process of inquiry but always put these in context.

c. The process, product, and purpose of scientific inquiry are intimately related.

Some curriculum materials distort the process of inquiry by separating it from the product. Moreover, an appreciation of both process and product remains limited unless we understand their purpose in terms of human interest. For example, when the City of London was being rebuilt after the Great Fire of 1666, Robert Hooke was appointed chief surveyor. His concern or purpose was with the rebuilding of the city. His interest in the elasticity and strength of substances complemented this concern and led him to carry out a variety of inquiries.

In general terms, the product of inquiry is conceptualized as a network of explanations that have an amazing power to explain and predict the way the natural world works. The precise nature of this network of explanations is difficult to conceptualize (and possibly contentious), but it's important to try because students do need to have some idea of what they are trying to learn. This curriculum presents three different types of explanation: generalizations that relate one pattern to another (e.g., wooden materials burn); generalizations that elaborate, often quantitatively, on a relationship (e.g., the wetter the wood, the slower it burns); and analogies and models that link generalizations and add an extra dimension of understanding (e.g., wood behaves as if it is a bundle of fibers stuck together).

d. The method of scientific inquiry and the assumptions on which it is based have evolved over the past 400 years.

Many portrayals of scientific inquiry are incomplete. This is especially true of those curriculum materials that emphasize the development of process skills. Many neglect the assumptions on which such inquiry is based.

For example, scientists assume that the world is regular and, in their experiments, give particular attention to reproducibility. But few curriculum materials, if any, give due attention to the idea of reproducibility (called *repeatability* in these materials). Without reproducibility, scientific inquiry as we know it would not exist. Reproducibility is a crucial test of a good experiment, yet it is ignored more often than not.

Many curriculum materials focusing on the process dwell heavily on the collection and manipulation of numerical data. But seldom do they ask, "Why do scientists use numbers?" or "Can good science be done without numbers?" These are crucial questions that also are ignored more often than not.

One further example: Seldom is it acknowledged that scientific research is undertaken by a community of scientists and that what counts as scientific knowledge is the consensus scientists hold about the best explanation of the way our world works—that knowledge, rather than being out there for the finding, is inside their heads. This widely accepted view of the nature of scientific knowledge is scarcely recognized in curriculum materials.

e. Scientific thinking is a refinement of everyday thinking.

This was Einstein's view, and these materials share this view. This is comforting, but it is nevertheless important to consider just how it is a refinement of everyday thinking.

The purpose of scientific activity is to produce a body of understanding that stands the test of time; it is about "knowing for sure." Scientists take pains to make sure they can trust their findings. This enables one scientist to build on and incorporate the findings of others in a common quest to understand how the universe works.

Scientific activity is careful and deliberate and sometimes probes areas of inquiry that everyday activity would ignore or take for granted. The carefully designed experiment is often a central element of this activity.

Scientific activity uses reductionist methods. It reduces complexity by systematically "pulling apart" a phenomenon and investigating each element in turn, with a view toward assembling a comprehensive understanding of the phenomenon.

Scientific activity is systematic and methodical. It is different from cooking, which uses trial and error.

Simple, elegant explanations and theories are preferred to convoluted ones, to which there are many exceptions and qualifications. For example, the early chemists put forward the idea of "phlogiston," an invisible flammable substance, to explain combustion. However, there were lots of problems with this theory: Sometimes phlogiston seemed to weigh a lot, and sometimes it appeared to weigh less than nothing. The puzzle was eventually solved by Lavoisier, who suggested that when something burned, it combined with the active part of air (oxygen). His simple and elegant theory explained everything and much more. Physicists today are on a quest to find a universal theory of gravitation and electromagnetic interactions.

Einstein's view of science as being a refinement of everyday thinking is also useful pedagogically. It suggests the goal of helping students refine or develop their everyday thinking capacity. To reach this goal, it would seem logical for the teacher to begin by revealing the students' everyday thinking about problem solving and then helping them construct an appreciation of how scientists solve problems. This pedagogical strategy—a constructivist strategy—is the theme of the next section.

Pedagogic Strategy

So how does one help students appreciate the art of solving scientific problems, become better scientific problem solvers, and gain an awareness of the way in which scientists have developed our understanding of natural phenomena? This was the central question that needed to be addressed when devising a suitable teaching strategy.

Central to the strategy finally adopted was the fairly obvious idea of actually challenging the students with meaningful problems to solve—problems they felt they could tackle with a view to the teacher subsequently helping them become better scientific problem solvers. These problems were selected after reviewing hundreds of students' projects in an attempt to identify their range of interests and the types of difficulty they encountered.

The strategy begins with the teacher introducing a problem. Considerable skill and sensitivity are needed to help the students find meaning in the problem, take ownership of it, and feel confident that solving the problem is within their capabilities. This step is important if the students are to accept the challenge of designing their own procedures. The students, in pairs or sometimes in small groups, are then given the task of finding a solution to the problem.

After they have attempted to solve a problem, the students are frequently provided with the opportunity to discuss how they tackled it. In doing so, they reflect on the procedures they used and make their procedures explicit. Making students aware of their thinking is an important precursor to their learning. Moreover, a teacher who elicits his or her students' ideas is in a powerful position to respond to their needs.

This then sets the stage for inviting students to compare how they set about solving the problem with how scientists might have tackled it. Finally, the students are encouraged to practice on a similar problem.

Typically, then, a lesson follows a four-stage sequence. Let us take an example. In Chapter 4, the lesson is "**Are Some Measures Better Than Others?" The lesson asks the question, "Which magnet is stronger?"

Stage 1: Attempting to Solve a Problem

The teacher introduces the problem by describing and maybe demonstrating the attempts of two students, Marie and Monique, to make magnets. After setting the scene and (hopefully!) gaining the students' interest, the teacher then challenges the students to help Marie and Monique find out which of two magnets is stronger. The students work in pairs. Each pair is provided with two magnets and access to assorted materials: paper clips, plotting compasses, thread, iron filings, rulers, elastic bands, and so on. As the students work, the teacher can gain some insight into their preliminary thinking.

Stage 2: Reflecting on Student Procedures

a. The students are asked to write to Marie and Monique with their recommendations about the best strength tests. Research indicates that having an audience for a report adds meaning to the task of writing up what they did.

b. They share and compare their solutions with others.

Here the students are implicitly invited to reconstruct their thinking when appropriate.

Stage 3: Comparing Student Procedures to Those Used by Scientists

A case study in which Marie and Monique visit a scientist is used as a vehicle for stimulating discussion about problems of measurement. Through this discussion, the students compare the procedures they devised with those favored by scientists. This leads to a consideration of the ideas of reliability and sensitivity.

Stage 4: Practicing

The students test the reliability and sensitivity of some of the procedures. There are many variations of this overall strategy. Here are three important ones:

a. In Stage 3, when possible, a case study of how a scientist tackled a similar problem is introduced. In this way, students learn about the experiments of people such as Galileo, Mendel, Lavoisier, Aristotle, Fleming, Redi, Newton, and Hooke.

b. In Stage 3, questions for discussion are often included so as to change reading from a passive experience to an interactive and thoughtful one. These questions are printed in italics and frequently found at the end of a paragraph. They provide an opportunity to take time out for a brief discussion.

c. Many teachers will use this book to help students undertake independent science projects and investigations, possibly with a view to participation in a science fair. Stage 4 frequently provides the opportunity for students to practice on the type of projects other students have actually chosen. Alternatively, if students are undertaking a project of their own (e.g., one of those described in Chapter 1, "Starting Points"), then Stage 4 provides an excellent opportunity for reviewing progress and applying the ideas encountered in the lesson.

This pedagogic strategy is based on the current constructivist view of learning, a learning theory that has gained ascendancy over the past 20 years to the point of being almost universally accepted (for example, it has been endorsed by Project 2061 of the AAAS). The strategy is similar to the one suggested for teaching scientific concepts in my recent book *Predict, Observe, Explain* (Haysom and Bowen 2010), which might prove to be a useful reference.

Inquiry and Student Independence

A Framework for K–12 Science Education (NRC 2012) has this to say about student independence:

> Students should have opportunities to plan and carry out several different kinds of investigations during their K–12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from the students' own questions. As they become more sophisticated, students also should have opportunities not only to identify questions to be researched but also to decide what data are to be gathered, what variables should be controlled, what tools or instruments are needed to gather and record data in an appropriate format, and eventually to consider how to incorporate measurement error in analyzing data. (p. 61)

In Canada, the *Common Framework of Science Learning Outcomes* (CMEC 1997) makes similar points.

Developing student independence involves the teacher in moving from a more structured classroom to a less structured one. It involves providing students with more and more opportunities to make choices. It involves the teacher in behaving less of an authority and more of a resource, who helps, facilitates and responds flexibly to the needs of students.

Some think that this can promote a more enjoyable classroom, lead to greater student involvement and motivation, and improve a student's self-confidence. Others believe that if teachers relinquish some of their academic authority, this might create classroom-management problems. Paradoxically, some students might resist being offered more freedom, preferring instead the security that structure provides. Either way, it is easier said than done. Nevertheless, it might be possible for a teacher to progressively offer the students more freedom of choice as the students gain confidence and determination in solving their own problems. It could be worth trying, and Table 1 might be of some use to those who wish to check the amount of structure provided in the various stages of inquiry.

Finally, the materials themselves are designed to facilitate the change from more structure to less. For example, the materials often invite discussion of how scientists have tackled a problem, a strategy that provides the teacher with the opportunity to distance herself from authority. Here is another example: In the Back to the Project items that conclude most of the lessons, there is often no need for the teacher to provide closure. Instead, the ideas that have been introduced can simply be allowed to continue to challenge the students. As was mentioned previously, the materials use a constructivist pedagogy, and one of the fundamental tenets of constructivism is that students are responsible for their own learning. It might be possible for a teacher to gradually offer the students more freedom of choice if the materials are used over three consecutive years.

Table 1: Stages of Inquiry and Increasing Student Independence

Stage of Inquiry	Teacher-Structured	Semi-Structured Increasing Student Independence	Independent Student
Idea for Inquiry (see Chapters 1 and 12)	The teacher assigns the Starting Point.	Student chooses from a list of Starting Points provided by the teacher.	Student identifies his or her own Starting Point.
Clarification of Idea or Preliminary Exploration (see Chapter 3)	The Starting Point is clarified by the teacher, who formulates questions for investigation.	The teacher helps clarify the problem by discussing it and asking questions.	The student carries out preliminary exploration, formulates questions, and makes decisions about a course of action to follow.
Design of Investigation (see Chapters 4, 5, and 6)	The teacher provides the student with a plan to follow, measurement procedures to use (if necessary), and variables to control.	The teacher indirectly assists the student with the design of the investigation and discusses problems of measurement and the control of variables.	The student designs the procedure for the investigation.
Collection of Data (see Chapter 7)	The teacher directs the student to check for reproduceability, to search for errors, and so on.	The teacher asks about reproduceability, sources of error, and so on.	The student independently checks for reproduceability and searches for errors.
Analysis and Interpretation of Data (see Chapters 8 and 9)	The teacher tells the student how to analyze the data and interprets the results.	With guidance from the teacher, the student tries to make sense of his or her results.	The student analyzes data and considers their meaning and significance.
Presentation of Investigation (see Chapter 10)	The teacher outlines how the student should present inquiry.	The teacher discusses alternative ways to present the inquiry.	The student decides how to present the inquiry.

Structure of the Curriculum

The curriculum begins with an invitation to the students to choose a practice project, a Starting Point (Chapter 1), and culminates with the students choosing a science fair project of their own (Chapter 12, "Generating Ideas for Projects").

Chapter 2, "An Overview of the Nature of Scientific Inquiry," provides an orientation to the way in which scientists approach a problem and a perspective on the nature of scientific inquiry, which is the practice of scientists.

The remaining 10 chapters each focus on a different aspect of scientific investigations—different scientific practices. I anticipate that as students carry out their warm-up projects (or projects of their own choosing), they will encounter problems similar to those introduced in these chapters. The chapters provide indirect help along the way. They are sequenced along a timeline from having an idea for an inquiry (Chapters 1 and 2) to clarifying the idea (Chapter 3) to designing an investigation (Chapters 4, 5, and 6) to collecting data (Chapter 7) to analyzing and interpreting data (Chapters 8 and 9) and, ultimately, to presenting the findings. This sequence, although seemingly logical at first glance, is frequently not followed in practice. Indeed, scientists seldom follow this process. It certainly isn't carved in stone, and teachers may well decide to change the order to help students with the problems they encounter.

Each of the three student books in the series follows this sequence of chapters, and the books progressively increase in complexity and difficulty as one proceeds from the first book to the last one. The ideas in the later books build on those presented in the earlier books and make greater cognitive demands on the students. Let us take a couple of examples.

Example 1

Chapter 5, "Variables and Their Control": This chapter, building on students' natural idea of fairness, introduces the idea of a fair test through the control of variables in the grades 5–8 book. Once a fair test has been achieved, then it is possible to move on to the grades 7–10 book to find out how one variable depends on another. Finally, in the grades 8–12 book, students are invited to examine the rather demanding problem of designing a boat hull, a project in which there are many interacting variables.

Example 2

Chapter 7, "Sources of Error": This chapter deals with sources of error. The grades 5–8 book focuses on errors of measurement and taking the average. The grades 7–10 book examines the problems of tracking down sources of error that arise from uncontrolled variables, and the grades 8–12 book deals with variables that one cannot control, such as those encountered when working with human subjects, animals, and plants. In the grades 8–12 book, Chapter 7 introduces statistics and sampling.

In the series, the lessons in the first book (grades 5–8) are marked with a single star (*), the lessons in the next book (grades 7–10) with two stars (**), and those in the final book (grades 8–12) with three stars (***). The series has been field-tested with middle school students—the one-star lessons with grade 6, the two-star lessons with grade 7, and the three-star lessons with grade 8.

If a teacher has access to all three books, the teacher would have extra flexibility to mix lessons to match the needs of his students. Indeed, a comprehensive course for mature students (grades 9–12) on the practices of scientists might use this lesson sequence: 1***, 2*, 2***, 3 (all lessons), 4 (all lessons), 5 (all lessons), 6 (all lessons), 7 (all lessons), 8**, 8***, 9 (all lessons), 10**.

Content Overview

	Progression, Level of Sophistication		
Chapter	**Grades 5–8 Book (*)**	**Grades 7–10 Book (**)**	**Grades 8–12 Book (***)**
1. Starting Points	• Paper Helicopters • What Makes Seeds Grow? • Etc. (2)	• Louis Braille's Invention • Archimedes' Pump • Etc. (2)	• Smoking Chimneys • Acid Rain and Pollution • Etc. (2)
2. An Overview of the Nature of Scientific Inquiry	• Beginner Scientists and Experienced Scientists (2)	• What Do Scientists Do? (3)	• Simplifying Complex Scientific and Technological Problems (2 or 3)
3. Science Without Numbers	• Wondering Why (2)	• Looking for Similarities and Differences (3 or 4)	• Searching for Patterns (4)
4. The Numbers Game	• Learning to Play the Numbers Game (2)	• Are Some Measures Better Than Others? (3)	• Designing Your Own Measures (4)
5. Variables and Their Control	• Being Fair (1)	• Finding Out How Much It Matters (2)	• Isolating Variables: Reducing Complexity (2)
6. Experiment Design	• Getting Experiments to Work: Repeatability (2)	• Designing Good Apparatus (2)	• Preparing Experiment Designs (1 or 2)
7. Sources of Error	• Taking the Average (1 or 2)	• Searching for Errors (1 or 2)	• Sampling: An Introduction (2)
8. Making Sense of Your Results	• Charting Your Data (2)	• Graphing Your Data (1 or 2)	• Interpreting Graphs (2)
9. Explanations	• Looking for Patterns and Trends: Generalizing (2 or 3)	• Getting Explanations That Fit (5)	• Deepening Your Understanding: Analogies and Models (3)
10. Sharing Your Findings	• Displaying Your Project (2)	• Writing Your Report (2)	• Talking About Your Project (1)
11. Judging Projects	• Checking for Quality (1)	• Suggesting Improvements (1)	• Making Judgments (1)
12. Generating Ideas for Projects	• Ideas From Previous Science Fairs (1)	• Ideas All Around You (1)	• Ideas From the Scientific Literature (1 or 2)

Note: The numbers in parentheses give an estimate of the number of 40-minute periods required to complete the lesson.

Be Safe!

It is important to set a good example and remind students of pertinent safety practices when they perform an experiment.

1. Always review Material Safety Data Sheets (MSDS) with students relative to safety precautions.
2. Remind students to only view or observe animals and not to touch them unless instructed to do so by the teacher.
3. Use caution when working with objects such as scissors, razor blades, electrical wire ends, knives, or glass slides. These items can be sharp and may cut or puncture skin.
4. Wear protective gloves and aprons (vinyl) when handling animals or working with hazardous chemicals.
5. Wear indirectly vented chemical-splash goggles when working with liquids such as hazardous chemicals. When working with solids such as soil, metersticks, glassware, and so on, safety glasses or goggles should be worn.
6. Always wear closed-toe shoes or sneakers in lieu of sandals or flip-flops.
7. Do not eat or drink anything when working in the classroom or laboratory.
8. Wash hands with soap and water after doing the activities dealing with hazardous chemicals, soil, biologicals (animals, plants, and so on), or other materials.
9. Use caution when working with clay. Dry or powdered clay contains a hazardous substance called silica. Only work with clean wet clay.
10. When twirling objects around the body on a cord or string, make sure fragile materials and other occupants are out of the object's path.
11. Use only non-mercury-type thermometers or electronic temperature sensors.
12. When heating or burning materials or creating flammable vapors, make sure the ventilation system can accommodate the hazard. Otherwise, use a fume hood.
13. Select only pesticide-free soil, which is available commercially for plant labs and activities.
14. Many seeds have been exposed to pesticides and fungicides. Wear gloves and wash hands with soap and water after an activity involving seeds.
15. Never use spirit or alcohol burners or propane torches as heat sources. They are too dangerous.
16. Use caution when working with insects. Some students are allergic to certain insects. Some insects carry harmful bacteria, viruses, and so on. Wear personal protective equipment, including gloves.
17. Immediately wipe up any liquid spills on the floor—they are slip-and-fall hazards.

Chapter 5:
Variables and Their Controls

Middle school students seem to have an intuitive grasp of how to proceed with consumer or product testing. They frequently choose projects such as "Which detergent removes stains best?" or "Which battery lasts longest?" or "Can people really tell the difference between Coke and Pepsi?" In carrying out projects like these, students seem to give attention to the idea of being fair.

This chapter builds on the idea of the fair test and introduces the notion of controlled experimental conditions. In the second lesson, Finding Out How Much It Matters, attention is focused on the systematic variation of one variable. We will also consider the problem of identifying and separating variables in complex situations.

The experiment is central to much of scientific inquiry. Through controlled experiments, scientists try to develop their understanding of a phenomenon by ascertaining which factors affect the phenomenon and the extent to which each factor makes a difference.

Here is an extract from the *National Science Education Standards* (NRC 1996):

> Design and conduct a scientific investigation. Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables. (p. 145)

Here is an extract from *A Framework for K–12 Science Education* (NRC 2012):

> Planning and designing such investigations require the ability to design experimental and observational inquiries that are appropriate to answering the question being asked or testing a hypothesis that has been formed. This process begins by identifying the relevant variables and considering how they might be observed, measured, and controlled (constrained by the experimental design to take particular values). (p. 59)

Chapter 5

5* BEING FAIR

Purpose

From an early age, children have a good idea of what being fair means. In a fair test, everything is treated in the same way (controlled), apart from that which is deliberately changed or varied. In this way, scientists can determine whether a change makes a difference.

Time Allocation

One 40-minute period

Apparatus and Materials

None required

Suggested Approach

1. The cartoon is designed to interest the students and help them develop a critical frame of mind. It should help them formulate questions (in small groups) about the experiments with the radishes and the glue.
2. Discuss the sections "Being Fair" and "Redi's Experiment."
3. Read about how the girls tried to control their hairspray experiment ("A Fair Test?"), and invite the students to respond to the questions at the end.
4. Ask the students to design fair tests for one of the projects described at the end of the lesson (a valuable homework assignment).

Note: If students are having difficulty with the first part of the lesson, it might be worth extending it, using the reaction time experiment ("Sampling: An Introduction") described in Chapter 7 of the book for grades 8–12. Give students the task of formulating the rules for a reaction time competition. In doing so, they will identify variables that might make a difference in the results.

5** FINDING OUT HOW MUCH IT MATTERS

Purpose

This lesson builds on the idea of a fair test (5*). After scientists have learned (through a controlled experiment) whether or not a variable makes a difference, they often proceed to find out how much difference it makes. This involves the design of a series of controlled experiments in which one factor is systematically varied.

Time Allocation

Two 40-minute periods

Apparatus and Materials

Each group of students (3 or 4 per group would be optimal) will need the following:

- About 4 ft. (2 lengths) of Hot Wheels track (affordable and found in many toy stores)

- Ball about 3 cm in diameter (e.g., a table tennis ball)
- Ruler
- Protractor

Suggested Approach

1. Introduce the task and briefly discuss the sort of procedures the students might use.
2. Ask them to complete the questions for discussion (possibly for homework).
3. Review some of their findings.
4. Invite the students to do the "Quick Quiz" and read the section "Scientists Want to Know How Much?" When reviewing their answers, you might like to demonstrate the effects of varying the mass of the pendulum bob and the cooling of mugs containing different amounts of water (use cans to get a more dramatic effect).
5. Finally, invite the students to respond to the problems from "Back to the Project."

5*** ISOLATING VARIABLES: REDUCING COMPLEXITY

Purpose

Many scientific, technological, and engineering problems are extremely complex. This is especially evident in such fields as meteorology and engineering. When scientists encounter complex problems, they often use a strategy of reductionism, which reduces complexity by studying the effects of different variables in isolation. This lesson introduces students to this strategy.

Time Allocation

Two 40-minute periods

Apparatus and Materials

None required (although the apparatus described in the case study may be worth demonstrating and using with some simple shapes)

Suggested Approach

1. Introduce the case study and set the task as a small-group assignment.
2. Review and discuss answers from two or three groups.
3. The section "How Scientists Approach Challenging Problems" is designed for interactive reading and discussion. The middle section, which involves designing experiments with dowel rods, may warrant individual or small-group work.
4. The problems in "Back to the Project" may be used to stimulate class discussion or as homework assignments.

Notes

a. At least 10 variables affect the speed of boats. In addition to those mentioned, students might suggest the following variables: the angle of the bow to the water, the surface area of the hull, and the width of the boat.

b. Most of the variables are connected. Some may be combined if surface area is considered to be just one variable, but this subtlety is probably best left unmentioned unless it is raised by the students. At first sight, the salinity of the water is a separate variable, but remember that boats ride higher in salty water. The finish of the boat is a separate variable.

c. The dowel rod offers the opportunity to study the effects of area of cross-section, length, and weight, though weight is a difficult variable to isolate.

d. Square or rectangular blocks provide a simple means of studying the effects of varying how much surface area is submerged. You can vary the weight by adding cargo. The use of the balls begins to address the problems of shape of bow and stem. Some interesting possibilities emerge if sections of the spheres are stuck onto the dowel rod.

Index

Index

Index

Index

SCIENCE FAIR WARM-UP

» LEARNING THE PRACTICE OF SCIENTISTS «

Teachers Guide

Even science fair enthusiasts may dread grappling with these two questions:

1. How can you organize many students doing many different projects at the same time?
2. How can you help students while giving them the freedom of choice and independence of thought that characterize genuine inquiry?

Answer these questions—and face science fairs without fear—with the help of the *Science Fair Warm-Up* series. The series' three student books each build on the ideas introduced in the previous book, and the problems in the later books are progressively more challenging. The series' field-tested material will help your students develop the inquiry skills to carry their projects through—whether they're middle schoolers preparing for their first science fair or high schoolers ready for very challenging investigations. This teachers guide lets you make best use of the original investigations and problem-solving exercises provided by each of the grade-appropriate student editions.

To help you meet your teaching goals, the series is based on the constructivist view that makes students responsible for their own learning and aligns with national standards and the *Framework for K–12 Science Education*. *Science Fair Warm-Up* will prepare both you and your students for science fair success. But even if you don't have a science fair in your future, the material can make your students more proficient with scientific research.

"An exciting publication that engages students and fills a need for innovative and conscientious teachers. Students and teachers are likely to encounter real science with the ideas, approaches, and questions the materials encourage." —Robert Yager, Professor Emeritus at the University of Iowa and past president of NSTA

Grades 5–12

NSTApress
National Science Teachers Association

PB328X2
ISBN: 978-1-936959-23-5

9 781936 959235