The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Wm. A. Wulf is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy’s purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. Wm. A. Wulf are chair and vice chair, respectively, of the National Research Council.
COMMITTEE ON HOW PEOPLE LEARN: A TARGETED REPORT FOR TEACHERS

JOHN D. BRANSFORD (Chair), College of Education, University of Washington
SUSAN CAREY, Department of Psychology, Harvard University
KIERAN EGAN, Department of Education, Simon Fraser University, Burnaby, Canada
SUZANNE WILSON, School of Education, Michigan State University
SAMUEL S. WINEBURG, Department of Education, Stanford University

M. SUZANNE DONOVAN, Study Director
SUSAN R. MCCUTCHEON, Research Associate
ALLISON E. SHOUP, Senior Project Assistant
ELIZABETH B. TOWNSEND, Senior Project Assistant
Preface

This book has its roots in the report of the Committee on Developments in the Science of Learning, *How People Learn: Brain, Mind, Experience and School* (National Research Council, 1999, National Academy Press). That report presented an illuminating review of research in a variety of fields that has advanced understanding of human learning. The report also made an important attempt to draw from that body of knowledge implications for teaching. A follow-on study by a second committee explored what research and development would need to be done, and how it would need to be communicated, to be especially useful to teachers, principals, superintendents, and policy makers: *How People Learn: Bridging Research and Practice* (National Research Council, 1999). These two individual reports were combined to produce an expanded edition of *How People Learn* (National Research Council, 2000). We refer to this volume as *HPL*.

In the present book, the goal is to take the *HPL* work to the next step: to provide examples of how the principles and findings on learning can be used to guide the teaching of a set of topics that commonly appear in the K-12 curriculum. As was the case in the original work (1999), the book focuses on three subject areas: history, mathematics, and science. Each area is treated at three levels: elementary, middle, and high school. Distinguished researchers who have extensive experience in teaching or in partnering with teachers were invited to contribute the chapters. The committee shaped the goals for the volume, and commented—sometimes extensively—on the draft chapters as they were written and revised. The principles of *HPL* are embedded in each chapter, though there are differences from one chapter to the next in how explicitly they are discussed.
Taking this next step to elaborate the HPL principles in context poses a potential problem that we wish to address at the outset. The meaning and relevance of the principles for classroom teaching can be made clearer with specific examples. At the same time, however, many of the specifics of a particular example could be replaced with others that are also consistent with the HPL principles. In looking at a single example, it can be difficult to distinguish what is necessary to effective teaching from what is effective but easily replaced. With this in mind, it is critical that the teaching and learning examples in each chapter be seen as illustrative, not as blueprints for the “right” way to teach.

We can imagine, by analogy, that engineering students will better grasp the relationship between the laws of physics and the construction of effective supports for a bridge if they see some examples of well-designed bridges, accompanied by explanations for the choices of the critical design features. The challenging engineering task of crossing the entrance of the San Francisco Bay, for example, may bring the relationship between physical laws, physical constraints, and engineering solutions into clear and meaningful focus. But there are some design elements of the Golden Gate Bridge that could be replaced with others that serve the same end, and people may well differ on which among a set of good designs creates the most appealing bridge.

To say that the Golden Gate Bridge is a good example of a suspension bridge does not mean it is the only, or the best possible, design for a suspension bridge. If one has many successful suspension bridges to compare, the design features that are required for success, and those that are replaceable, become more apparent. And the requirements that are uniform across contexts, and the requirements that change with context, are more easily revealed.

The chapters in this volume highlight different approaches to addressing the same fundamental principles of learning. It would be ideal to be able to provide two or more “HPL compatible” approaches to teaching the same topic (for example, the study of light in elementary school). However, we cannot provide that level of specific variability in this already lengthy volume. Nevertheless, we hope that common features across chapters, and the variation in approach among the chapters, are sufficient to provide instructive insights into the principles laid out in How People Learn.

This volume could not have come to life without the help and dedication of many people, and we are grateful to them. First and foremost, the committee acknowledges the contributions of Robbie Case, who was to have contributed to the mathematics chapters in this volume. Robbie was at the height of a very productive career when his life came to an unexpected end in May 2000. Robbie combined the very best in disciplinary research and attention to the incorporation of research findings into classroom tools
to support teaching and learning. In this respect, he was a model for researchers interested in supporting improved educational practice. The mathematics chapters in this volume are marked by Robbie Case's influence.

The financial support of our sponsors, the U.S. Department of Education and the President’s Circle of the National Academy of Sciences, was essential. We appreciate both their support and their patience during the unexpectedly long period required to shape and produce so extensive a volume with so many different contributors. Our thanks to C. Kent McGuire, former assistant secretary of the Office of Education Research and Improvement for providing the initial grant for this project, and to his successor and now director of the National Institute for Education Sciences, Grover J. Whitehurst; thanks are due as well to Patricia O’Connell Ross, Jill Edwards Staton, Michael Kestner, and Linda Jones at the Department of Education for working with us throughout, and providing the time required to produce a quality product.

This report is a somewhat unusual undertaking for the National Research Council in that the committee members did not author the report chapters, but served as advisers to the chapter authors. The contributions of committee members were extraordinary. In a first meeting the committee and chapter authors worked together to plan the volume. The committee then read each draft chapter, and provided extensive, and remarkably productive, feedback to chapter authors. As drafts were revised, committee members reviewed them again, pointing out concerns and proposing potential solutions. Their generosity and their commitment to the goal of this project are noteworthy.

Alexandra Wigdor, director of the Division on Education, Labor, and Human Performance when this project was begun, provided ongoing guidance and experienced assistance with revisions. Rona Brière brought her special skills in editing the entire volume. Our thanks go to Allison E. Shoup, who was senior project assistant, supporting the project through much of its life; to Susan R. McCutchen, who prepared the manuscript for review; to Claudia Sauls and Candice Crawford, who prepared the final manuscript; and to Deborah Johnson, Sandra Smotherman, and Elizabeth B. Townsend, who willingly provided additional support when needed. Kirsten Sampson Snyder handled the report review process, and Yvonne Wise handled report production—both challenging tasks for a report of this size and complexity. We are grateful for their help.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council’s Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards.
for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following individuals for their review of this report: Jo Boaler, Mathematics Education, School of Education, Stanford University; Miriam L. Clifford, Mathematics Department, Carroll College, Waukesha, Wisconsin; O.L. Davis, Curriculum and Instruction, The University of Texas at Austin; Patricia B. Dodge, Science Teacher, Essex Middle School, Essex Junction, Vermont; Carol T. Hines, History Teacher, Darrel C. Swope Middle School, Reno, Nevada; Janis Lariviere, UTeach—Science and Mathematics Teacher Preparation, The University of Texas at Austin; Gaea Leinhardt, Learning Research and Development Center and School of Education, University of Pittsburgh; Alan M. Lesgold, Office of the Provost, University of Pittsburgh; Marcia C. Linn, Education in Mathematics, Science, and Technology, University of California, Berkeley; Kathleen Metz, Cognition and Development, Graduate School of Education, University of California, Berkeley; Thomas Romberg, National Center for Research in Mathematics and Science Education, University of Wisconsin–Madison; and Peter Seixas, Centre for the Study of Historical Consciousness, University of British Columbia.

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the report before its release. The review of this report was overseen by Alan M. Lesgold, University of Pittsburgh. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authors, the committee, and the institution.

John D. Bransford, Chair
M. Suzanne Donovan, Study Director
## Contents

1 Introduction  
   *M. Suzanne Donovan and John D. Bransford*  
   A Fish Story, 2  
   Learning Environments and the Design of Instruction, 12  
   Putting the Principles to Work in the Classroom, 20  
   Intent and Organization of This Volume, 21  
   Notes, 25  
   References, 26

### Part I:  
#### History

2 Putting Principles into Practice: Understanding History  
   *Peter J. Lee*  
   History and Everyday Ideas, 33  
   Substantive Concepts, 61  
   History That Works, 65  
   Notes, 73  
   References, 74

3 Putting Principles into Practice: Teaching and Planning  
   *Rosalyn Ashby, Peter J. Lee, and Denis Shemilt*  
   The Reality Test, 80  
   Working with Evidence: Pilgrim Fathers and Native Americans, 84  
   Working with Evidence: The St. Brendan’s Voyage Task, 119
Appendix 3A: Implications for Planning, 164
Notes, 177
References, 177

4 “They Thought the World Was Flat?”: Applying the Principles of How People Learn in Teaching High School History
Robert B. Bain
Where to Begin? Transforming Topics and Objectives into Historical Problems, 181
Designing a “History-Considerate” Learning Environment: Tools for Historical Thinking, 199
Conclusion, 209
Acknowledgments, 210
Notes, 211
References, 212

Part II: Mathematics

5 Mathematical Understanding: An Introduction
Karen C. Fuson, Mindy Kalchman, and John D. Bransford
Principle #1: Teachers Must Engage Students’ Preconceptions, 219
Principle #2: Understanding Requires Factual Knowledge and Conceptual Frameworks, 231
Principle #3: A Metacognitive Approach Enables Student Self-Monitoring, 236
Next Steps, 243
Notes, 246
References, 246
Suggested Reading List for Teachers, 256

6 Fostering the Development of Whole-Number Sense: Teaching Mathematics in the Primary Grades
Sharon Griffin
Deciding What Knowledge to Teach, 259
Building on Children’s Current Understandings, 267
Acknowledging Teachers’ Conceptions and Partial Understandings, 279
Revisiting Question 2: Defining the Knowledge That Should Be Taught, 281
How Can This Knowledge Be Taught?: The Case of Number Worlds, 282
What Sorts of Learning Does This Approach Make Possible?, 302
CONTENTS

Summary and Conclusion, 305
Acknowledgments, 306
Notes, 306
References, 306

7 Pipes, Tubes, and Beakers: New Approaches to Teaching the Rational-Number System
   Joan Moss
   Rational-Number Learning and the Principles of How People Learn, 312
   Instruction in Rational Number, 319
   Conclusion: How Students Learn Rational Number, 341
   Notes, 343
   References, 345

8 Teaching and Learning Functions
   Mindy Kalchman and Kenneth R. Koedinger
   Addressing the Three Principles, 359
   Teaching Functions for Understanding, 373
   Summary, 389
   Acknowledgments, 391
   Notes, 392
   References, 392
   Other Relevant Readings, 393

Part III: Science

9 Scientific Inquiry and How People Learn
   John D. Bransford and M. Suzanne Donovan
   Principle #1: Addressing Preconceptions, 399
   Principle #2: Knowledge of What It Means to “Do Science,” 403
   Principle #3: Metacognition, 407
   The How People Learn Framework, 411
   Conclusion, 415
   Notes, 416
   References, 416

10 Teaching to Promote the Development of Scientific Knowledge and Reasoning About Light at the Elementary School Level
   Shirley J. Magnusson and Annemarie Sullivan Palinscar
   The Study of Light, 422
   The Study of Light Through Inquiry, 426
Supporting Learning Through Cycles of Investigation, 460
The Role of Subject-Specific Knowledge in Effective Science Instruction, 467
Conclusion, 469
Notes, 470
References, 472

11 Guided Inquiry in the Science Classroom
James Minstrell and Pamela Kraus
The Unit: The Nature of Gravity and Its Effects, 477
Summary, 511
Notes, 512

12 Developing Understanding Through Model-Based Inquiry
James Stewart, Jennifer L. Cartier, and Cynthia M. Passmore
Genetics, 516
Developing Darwin’s Model of Natural Selection in High School Evolution, 540
Classroom Environments That Support Learning with Understanding, 555
Summary, 561
Notes, 562
References, 563

A Final Synthesis:
Revisiting the Three Learning Principles

13 Pulling Threads
M. Suzanne Donovan and John D. Bransford
Engaging Resilient Preconceptions, 569
Organizing Knowledge Around Core Concepts, 575
Supporting Metacognition, 577
Principles of Learning and Classroom Environments, 586
Notes, 588
References, 589
Other Resources, 590

Biographical Sketches of Committee Members and Contributors, 591

Index, 597
How Students Learn

HISTORY, MATHEMATICS, AND SCIENCE
IN THE CLASSROOM