Brain-powered science: teaching and learning with discrepant events / By Thomas O'Brien. 

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Contents

Acknowledgments........................................................................................................vi
About the Author...........................................................................................................ix
Introduction ..................................................................................................................xi
Science Education Topics ............................................................................................xxv

Section 1: Introduction to Interactive Teaching and Experiential Learning

Activity 1  Analogies: Powerful Teaching-Learning Tools ........................................3
Activity 2  Möbius Strip: Connecting Teaching and Learning .................................15
Activity 3  Burning a Candle at Both Ends: Classrooms as Complex Systems .......25

Section 2: Human Perception as a Window to Conceptions

Activity 4  Perceptual Paradoxes: Multisensory Science and Measurement ..........37
Activity 5  Optical Illusions: Seeing and Cognitive Construction ..........................47
Activity 6  Utensil Music: Teaching Sound Science .................................................63
Activity 7  Identification Detectives: Sounds and Smells of Science .....................73

Section 3: Nature of Cognition and Cognitive Learning Theory

Activity 8  Two-Balloon Balancing Act: Constructivist Teaching ........................87
Activity 9  Batteries and Bulbs: Teaching Is More Than Telling ............................97
Activity 10  Talking Tapes: Beyond Hearing to Understanding ................................109
Activity 11  Super-Absorbent Polymers: Minds-On Learning and Brain “Growth” ...119
Activity 12  Mental Puzzles, Memory, and Mnemonics: Seeking Patterns ..............131
Activity 13  Sound Tube Toys: The Importance of Varying Stimuli .........................141
Activity 14  Convection: Conceptual Change Teaching ........................................153
Activity 15  Brain-Powered Lightbulb: Knowledge Transmission? ........................163
Contents

Activity 16 Air Mass Matters: Creating a Need-to-Know ........................................... 171
Activity 17 3D Magnetic Fields: Making Meaningful Connections .............................. 179
Activity 18 Electric Generators: Connecting With Students .................................. 189
Activity 19 Static Electricity: Charging Up Two-by-Four Teaching ......................... 201
Activity 20 Needle Through the Balloon: Skewering Misconceptions ..................... 211
Activity 21 Happy and Sad Bouncing Balls: Student Diversity Matters .................... 221
Activity 22 Electrical Circuits: Promoting Learning Communities ......................... 233
Activity 23 Eddy Currents: Learning Takes Time .................................................... 241
Activity 24 Cognitive Inertia: Seeking Conceptual Change ...................................... 251
Activity 25 Optics and Mirrors: Challenging Learners’ Illusions ............................... 259
Activity 26 Polarizing Filters: Examining Our Conceptual Filters ............................ 267
Activity 27 Invisible Gases Matter: Knowledge Pours Poorly .................................. 275
Activity 28 The Stroop Effect: The Persistent Power of Prior Knowledge ................... 285
Activity 29 Rattlebacks: Prior Beliefs and Models for Eggciting Science ................. 293
Activity 30 Tornado in a Bottle: The Vortex of Teaching and Learning .................... 301
Activity 31 Floating and Sinking: Raising FUNdamental Questions ......................... 309
Activity 32 Cartesian Diver: A Transparent but Deceptive “Black Box” .................. 321
Activity 33 Crystal Heat: Catalyzing Cognitive Construction .................................. 331

Appendix A
Selection Criteria for Discrepant Events and Analogical Activities .......................... 343
Includes Connections to National Science Education Standards

Appendix B
The 5E Teaching Cycle: An Integrated Curriculum-Instruction-Assessment Model ........ 355

Appendix C
Science Content Topics ............................................................................................... 361
Research Cited .............................................................................................................. 367
Index ............................................................................................................................ 377
I owe an immeasurable debt of gratitude to the great science teachers whom I have had the pleasure to learn from and to work with over the years.

My initial inspiration to become a science teacher came from Dan Miller, my high school chemistry and physics teacher and student-teaching mentor. Dan’s frequent use of demonstrations and his emphasis on the historical evolution of theories made science both fun and mentally engaging. His gift of the book *Tested Demonstrations in Chemistry*, edited by Hubert Alyea and Fred Dutton and now out of print, catalyzed my interest in exploring the science behind the “magic” of science demonstrations.

When I was an undergraduate student at Thomas More College, the chemistry faculty supported my development of “edu-taining” Chemistry Is Magical programs for elementary classrooms. At the beginning of my work as a secondary science teacher, I was encouraged by Mickey Sarquis and the Cincinnati section of the American Chemical Society (ACS) to develop the skills and confidence to “teach teachers” via the Expert Demonstrator Training Affiliate program.

Later, my mentor at the University of Maryland-College Park, Dr. Henry Heikkinen, guided my dissertation study of a NSF-funded Institute for Chemical Education summer professional development program on chemical demonstrations. Henry’s expertise as a writer, editor, and science teacher educator also facilitated my transition to becoming a full-time science teacher educator through early development work on the ACS’s Chemistry in the Community textbook. Twenty years later, his insightful critique and encouragement helped me to frame the dual focus of this book: discrepant-event science activities and their use as analogies for science teacher education.

As a professor at Binghamton University, I’ve benefited from co-teaching grant-funded summer institutes with wonderful colleagues in all four of our science departments. Physicists Andy Telesca (who also reviewed early versions of this book) and Dr. Carl Stannard were especially supportive at the early stage of my development of the dual focus pedagogical strategy. Informal feedback from hundreds of preservice and inservice science teachers has enabled me to refine this approach. I especially appreciate the meticulous review of the science explanations in this book by my former doctoral student, Dr. Douglas Green.

(continued)
I would also like to acknowledge the many scientists and science teacher educators whose independent development of discrepant-event demonstrations and analogies is the foundation of my synthesis of these two teaching strategies. Nearly every science activity in this book has a history that goes back to books published at least 60 years ago; a few activities even go back as far as the late 1800s. Isaac Newton’s acknowledgment that he “stood on the shoulders of Giants” is especially relevant with my book.

Finally, I would like to thank my wife and children for their encouragement and support. Everyone’s children deserve the very best education that we can provide as we continually strive to grow as both teachers and learners.
Dr. Thomas O’Brien’s 33 years in science education began in K–12 schools, where he taught general, environmental, and physical sciences and high school chemistry. For the last 23 years, he has directed the preservice and inservice, graduate level, science teacher education programs of the School of Education at Binghamton University (State University of New York/SUNY). His master’s-level courses include Philosophical and Theoretical Foundations of Science Teaching, Curriculum and Teaching in Science, and Elementary Science Content and Methods. He also supervises the student teaching practica. In addition, he teaches a cross-listed doctoral/post-master’s educational leadership course.

Concurrent with and subsequent to earning a MA and a PhD in Curriculum and Instruction/Science Education at the University of Maryland-College Park, Dr. O’Brien served as a curriculum development specialist and teacher’s guide editor on the first edition of the American Chemical Society’s Chemistry in the Community (ChemCom) (1988) textbook and as the co-author of the New York Science, Technology & Society Education Project Teacher Guide (1996).

As a science teacher professional development specialist, he has co-taught 20 summer institutes, including national programs of the Institute for Chemical Education and state and regional programs funded by grants from the National Science Foundation, the Howard Hughes Medical Institute, and the New York State Education Department, among others. He has received awards for excellence in teaching and/or service from the American Chemical Society (for National Chemistry Week programs), the New York State Association of Teacher Educators, the SUNY chancellor, and the New York State Science Education Leadership Association. These grants and awards are a reflection of collaborations with university-based colleagues and of what he has learned with and from the large number of K–12 teachers he has had the privilege to serve.
Introduction

As current (or future) grades 5–12 science teachers, professional development specialists, or college-level science teacher educators, you have both the privilege and responsibility of asking your students and colleagues to join you as active, lifelong learners. This book invites you to engage in science that involves both hands-on play and minds-on mental processing. The 33 activities will lead you to critically examine and translate into practice your ever-evolving understanding of science and both the science and the art of science teaching. The “dual-purpose” activities—so called because they address science content and science education—are made up of two components:

1. **Discrepant-event science activities for use both in grades 5–12 classrooms and as models of inquiry-oriented science lessons for use in preservice classes and inservice professional development settings.**

   Whether done as a hands-on activity or demonstration, the discrepant event’s surprising, often counterintuitive outcome creates cognitive disequilibrium that temporarily throws learners mentally off-balance. For example nearly everyone “knows” that a sharp needle will pop a balloon, but in Activity #20 learners observe a long, sharp needle skewer a balloon without bursting the balloon. The unexpected outcome of such a discrepant event generates a need-to-know that motivates learners to thoughtfully reconsider their prior conceptions.

   Discrepant-event activities can be used anywhere in a unit. They are especially effective for diagnostic and formative assessment of learners’ evolving mix of science conceptions and misconceptions. Teaching science via multisensory experiences with live science phenomena also models the nature of science and contributes to memorable and transferable learning.

   The activities were selected to meet the six criteria of being safe, simple, economical, enjoyable, effective, and relevant for both teachers and their students (see Appendix A for a discussion of the criteria).

2. **“Visual participatory analogies”—that is, visual science education analogies—to catalyze the teacher-as-student’s creative use of research-informed science education principles.**

   Teachers commonly use verbal analogies to help students understand new, unfamiliar science concepts in terms of more familiar, better-understood ones (e.g., the cell *is like* a factory). Unfortunately, teachers
themselves are not typically provided similar conceptual scaffolds when
ty they become students in science education courses or professional
development programs. Visual participatory analogies are a new instructional
strategy developed by the author for teaching education theory to teach-
ers. With this strategy, teachers interactively participate with discrepant
science phenomena in ways that metaphorically help them bridge the
gap between science education theory and practice. For example, Activity #2 uses hands-on play with a Möbius strip as a visual participatory
analogy for the interactive nature of teaching and learning.

Your participation as teacher-as-learner-experimenter (rather than simply
passive reader) in these minds-on activities will lead you to question, and help
you to revise, your implicit assumptions about the nature of science, teaching,
and learning. At the same time, you will develop expertise with activities that
you can use with your own students. The dual-purpose activities thus allow
you to unlock two doors with one key—the doors to your own learning and
to your students’ learning.

At this point, if you have a burning desire for a direct experience with this
science content–science education approach, go directly to a sample activity
(e.g., Activity #3, “Burning a Candle at Both Ends: Classrooms as Complex
Systems”) right now and read the remainder of this Introduction after you
have worked and played through the activity. This book does not need to be used
in a strictly linear, front-to-back sequence with your students. Alternatively, you can
read this Introduction (which also describes the book’s organizational struc-
ture and the activity format), review the related research cited in the Appen-
dixes, and then proceed to activities #1 and #2. These first two activities are
introductions to the use of analogies and the idea of interactive teaching and
learning that are featured in all subsequent activities.

This book attempts to bridge the gaps between scholarly cognitive science
education research, national standards, and teacher-friendly activity books.
It asks you to alternate between the roles of student-learner and teacher–
reflective practitioner. I hope you will have as much fun with these dual-
purpose activities as I have had in developing them during the course of my
many years of working with teachers. A second volume is currently under
development.
Ways to Use This Book

Preservice Science Methods Courses

This book can be used in preservice science methods course as a supplement to middle and secondary methods textbooks that convey information about constructivist teaching. I believe that every methods class should be a lively, do-as-I-do exemplar of science inquiry approaches. As such, this book’s 33 discrepant-event activities (and over 100 extension activities) can be modeled by the instructor and used both in student-presented microteaching lessons and as a resource for fieldwork experiences and student teaching. The science education analogy associated with each activity can be discussed in the methods class and further explored in online forums to emphasize learning as an act of minds-on cognitive construction.

Grades 5–12 Science Classes

Teachers in grades 5–12 science classes can read, practice, adapt, implement, videotape, self-analyze, and further refine the book’s model science inquiry lessons. The science content information and science education analogy associated with each activity provide a broad context for the theoretical foundation of minds-on science teaching. Rather than merely being another source of neat activities to add to one’s bag of tricks, this book is designed to encourage teachers to critically examine some of their own favorite activities to see how to increase the activities’ inquiry potential or how to connect the activities to “big ideas” and scientific habits of mind.

Professional Development for Teachers

This book can also be used in collaborative, teachers-helping-teachers professional development. Whether you are a preservice, novice inservice, or veteran teacher, and whether you majored in science as an undergraduate or not, your own career-long, inquiry-based learning is essential to maintain your professional vitality. Increasingly, state and local school district policies and professional organizations such as the National Science Teachers Association are promoting and supporting continuous professional development (NSTA 2006, 2007a).

In fact, the professional development literature describes a wide variety of models for inservice teacher learning (Banilower et al. 2006; Loucks-Horsley et al. 1998; NRC 2001a; NSTA 2006, 2007a, 2007c; Rhoton and Bowers 2003; Yager 2005). Informal, one-to-one peer collaborations that share the wisdom of practice that resides in any school are too often an untapped resource for professional growth and curricular change. Pairs or small teams
Introduction

of teachers can use the activities in this book as starting points for informal “lesson study” (Stigler and Hiebert 1999). On a larger scale, with financial and logistical support from schools and districts, teachers in an entire science department could work together to refine one another’s teaching by visiting one another’s classrooms to model and critique lessons.

Other forms of professional development rely more on the leadership of a “master teacher.” For instance, districts are increasingly supporting mentor–new teacher pairings and science specialist teachers to lead study groups. Additionally, grant-funded collaborations with scientists and science teacher educators at the college level may provide funding and expertise for an academic year of Saturday Science Seminars, for summer institutes, and for specially targeted graduate-level courses.

Teachers are justifiably skeptical about one-shot workshops run by “outside experts,” and research indicates that these workshops rarely result in much more than short-lived motivational boosts. That said, even these quick-fix presentations can serve a catalytic role if they are followed by job-embedded support that helps teachers transfer the lessons learned into their science classrooms.

Other Considerations

If this book is used in a professional development course or program, it is best if the majority of the teacher-learners experience the activity “live” before reading the activity. Inquiry-based science teaching is based on the premise that prematurely giving answers (before engaging the learners with phenomena that raise questions for them to explore) can kill curiosity and limit learning effort and outcomes (NSTA 2004). However, if used in a self-study context, some of the element of surprise will necessarily need to be sacrificed. Even here, individual teacher-learners are encouraged to attempt to answer the questions embedded in the activities—by actually doing the activity—before reading the answers, which are intentionally placed at the end of each activity.

Most activities can be modeled in 10–20 min. when used with teachers as model science inquiry lessons or as science education analogies. With time so limited in most professional development settings, the activities are designed to be easy to set up, execute, and clean up. When used as science inquiry activities with grades 5–12 students, completing and processing the activities could take up to a full class period and would optimally be placed in an integrated instructional unit of related concepts and activities that would extend over a 1–2 week period (e.g., using the 5E Teaching Cycle: Engage, Explore, Explain, Elaborate, Evaluate; see Appendix B for a discussion of this teaching cycle).
Organizational Structure of the Book

This book’s 33 interactive, experiential learning activities are clustered into three sections, which are discussed below. Professional development specialists and college-level science teacher educators may wish to use the activities as a framework for either a series of professional development sessions or a more formal course. The major theme of the nature of science, teaching, and learning as informed by cognitive science research runs through all the activities (Aicken 1991; Bybee 2002; Cocking, Mestre, and Brown 2000; Lederman 1992, 1999; McComas 1996; Michaels et al. 2008; NRC 2007; NSTA 2000). The individual activities also can be used as independent stand-alones. Individual science teachers not affiliated with a course or professional development program may wish to use the special Science Content Topics section (pages 361–365) to select activities that match their grades 5–12 instructional scope and sequence. In this case, the science education themes will be encountered on a need-to-know basis in the course of regular classroom teaching.

Section 1. Introduction to Interactive Teaching and Experiential Learning

This short, foundation-setting section (activities #1–#3) introduces analogies as a cognitive tool and instructional strategy for interactive teaching and learning. The three activities use science education analogies to challenge teachers to consider alternative ways of seeing their relationship with learners and to consider the power of inquiry-oriented, curriculum-embedded assessment.

Activity #1 is the only one in the book that is not framed around a discrepant-event activity (although teachers may want to adapt the activity to teach their students about the complementary roles and responsibilities of teachers and students). It provides a concrete example and model of how to effectively use analogies to help learners to construct well-articulated understandings and avoid generating misconceptions. References are provided to support teachers’ ongoing use of analogies to help students understand nonobservable, abstract, or otherwise conceptually difficult science concepts in terms of more easily visualized, familiar phenomena and processes. Activity #2 introduces the idea of interactive, hands-on explorations (HOE) via a simple paper-and-pencil puzzle that asks learners to predict-observe-explain (POE). Activity #3 demonstrates how guided inquiry can uncover the science behind simple magic tricks.
Introduction

Section 2. Human Perception as a Window to Conceptions
These four activities (#4–#7) each include a number of mini-investigations that encourage learners to playfully explore some of the strengths and limitations of human perceptions (i.e., seeing, hearing, tasting, smelling, and heat flow and pressure-sensitive touching). Humans perceive, process (i.e., reconstruct and conceive), retain, and retrieve only the small portion of external reality that their sensory systems have evolved to detect, based on the selective, adaptive advantages provided (i.e., we notice on a "need-to-notice" basis). Also, to some extent, we perceive what we expect to perceive based on past experiences and preconceptions; human observations are always somewhat theory-laden. As such, our senses can be viewed analogically as tinted or foggy windows that allow small segments of filtered, external reality to enter into human consciousness and form the raw material for our conceptions (and possible misconceptions) about the nature of reality. Understanding our species-specific sensory limitations and individual attention deficits and learning how to design and use technology to help us extend the range, sensitivity, and reliability of our perceptions are central to the nature, history, and ongoing evolution of science that relies on valid, reliable, and “unbiased” empirical evidence.

Four major principles of cognitive learning theory are experientially developed through the 26 activities (#8–#33) that make up this major section of the book.

1. Knowledge transmission and passive reception models of teaching and learning are “unquestioned answers” that underlie common schooling practices that overemphasize teaching as telling and learning as listening (Michael and Modell 2003). By contrast, the research-validated idea of learning as a minds-on act of cognitive construction has the power to transform science education. Three hands-on explorations (activities #8–#10) are used to challenge outdated learning theories and provide multisensory experiences that support a more learner-active, constructivist model of understanding (which is further developed in subsequent activities).

2. Learning is a psychologically active, inside-out and outside-in process that is built on two-way interactions between and among individual minds and external learning environments. As such, learning depends on unique intrapersonal factors, interpersonal interactions (i.e., teacher ↔ learners and learners ↔ learners), and intentionally designed educational contexts. Effective teaching activates learners’ attention and catalyzes cognitive
processing. This general idea is introduced with two activities (#11–#12) and then experientially expanded on in the form of seven approaches that teachers can use to increase their pedagogical powers and instructional effectiveness (14 activities; #13–#26). These seven approaches might be viewed analogically as “weapons of mass instruction” that create pedagogical shock and awe to cause learners to pause, perceive, and ponder:

- Novelty/Changing Stimuli (activities #13–#14)
- Puzzles and Discrepant or Counterintuitive Events (activities #15–#16)
- Cognitive Connections and Meaningfulness (activities #17–#18)
- Multisensory Experiences and Multiple Contexts (activities #19–#20)
- Emotional Engagement, Connections, and Relevance (activities #21–#22)
- Adequate Time for Learning (activities #23–#24)
- Psychological Rewards (Gain/Pain or Benefit/Cost Ratio) (activities #25–#26)

3. Learners’ prior knowledge (including preconceptions and/or misconceptions) and cognitive inertia (or “conservatism”) may play a constructive, foundational role or a restrictive, limiting role relative to conceptual changes. Just as a solid house cannot be built on a weak foundation, new mental constructions will only stand the test of time if they are built on solid conceptual antecedents. Effective teachers activate and diagnostically assess learners’ preinstructional understanding to check for valid precursor ideas, experiential and conceptual holes, and misconceptions. Although many new ideas can be readily assimilated in the context of preexisting ones, new knowledge often requires conceptual accommodation whereby the learners’ prior conceptual networks must change for the new information to fit into the picture and make sense (activities #27–#29).

4. Effective science instruction catalyzes cognitive construction and builds a foundation for more independent learning by inviting inquiry rather than by indoctrinating. The last four activities (activities #30–#33) recapitulate the book’s major theme of interactive teaching-learning that supports learners’ active, minds-on cognitive construction. FUN and MENTAL activities that engage learners with discrepant phenomena, raise questions for exploration that demand explanation, and are rich in possibilities for elaboration are a powerful means of achieving this objective.
Format Used in Each Activity

Each of the 33 activities has the following format.

**Title**
This is intended to forecast the science content and science education content foci of the activity.

**Expected Outcome**
This section is a short description of the setup and expected result of the activity.

**Science Concepts**
This section briefly discusses the science concepts exhibited by the discrepant event. The author assumes that teachers reading this book are at least somewhat familiar with the underlying science concepts; will develop a deeper understanding through the inquiry questions and answers built into the Procedure and Debriefing sections; and/or can readily obtain additional background information via the Extensions and Internet Connections sections. The activities cut across physical, life, and Earth science concepts with an emphasis on foundational physical science concepts that lend themselves to shorter, mini-experiments and science education analogies. That said, over half of the activities contain a substantive link to biological analogies and applications (see Science Content Topics, pp. 361–365).

**Science Education Concepts**
When used with teachers (as the targeted learners), each discrepant-event science activity also serves as a visual participatory analogy—or science education analogy—for a science education principle. The intent is to create a common experiential foundation for subsequent collegial conversations and collaborations on the science and art of minds-on science teaching strategies. The long-range goal of the activities is to increase teachers’ science content knowledge and pedagogical content knowledge *simultaneously* (Cochran 1997; Shulman 1986).

Having several different activities for each science education principle allows both for instructional flexibility and for key ideas to be introduced, reinforced, and extended in different learning contexts with different analogies. If time permits, experiencing and critiquing multiple analogies for the same science education principle will enable teachers to form a richer, triangulated understanding.* Alternatively, a given activity might be modeled in *

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*Triangulate refers to the advantage of using multiple methods or approaches to lead to rich, nuanced answers to a given question. Because any single analogy has its limitations in explaining a given target, when teachers use multiple analogies they help students to develop a more complete understanding of a given scientific concept than they would if only one analogy were used.
a professional development program and teachers could be asked to test-out additional related activities in their classrooms before a second, follow-up session in which they critique and improve the activities.

Materials
This is a list of the required and optional materials needed to complete the activity. Many activities can be done as either an individual hands-on exploration or as teacher or participant-assisted demonstrations, depending on the availability of materials, the time constraints, and instructional setting (i.e., professional development versus grades 5–12 classrooms). Most of the activities use common materials, but representative suppliers (and costs) are cited to facilitate easy ordering in cases where unique science equipment or “toys” are used. Although the author has found the cited suppliers to be cost-competitive, no endorsement of particular companies is intended. Additionally, as all prices are subject to change, readers of this book are encouraged to check with the science supply companies used by their local school districts.

Points to Ponder
Each activity includes several powerful quotes from famous scientists, philosophers, or educators. Serious, sustained attention to the history and philosophy of science (HPS) in the K–12 curriculum is called for by research and policy documents (AAAS 1993; Matthews 1994; NRC 1996). Arguments for including more HPS in science courses include the following:

1. Cognitive development (i.e., the idea that a student’s cognitive ontogeny at times recapitulates the history of science phylogeny with respect to limited applicability models and misconceptions)
2. The need for a science-and-technology-literate citizenry that understands the nature and evolution of science
3. The benefits of situating and contextualizing science as a human endeavor that both affects and is affected by multicultural, historical forces

Brief historical quotes cannot do justice to HPS, but they can serve as catalysts to teachers to explore other HPS resources (e.g., Asimov 1976; Hakim 2004, 2005, 2007; Hellemans and Bunch 1988; Gribbin 2002; Silver 1998). The discussion questions in the Debriefing sections are explicitly linked to the quotes to raise HPS awareness and interest.
Procedure
This section includes the functional description of one or two possible ways of doing the activity. As needed, separate descriptions are provided for two settings: “When Working With Teachers” (i.e., teachers experiencing the activity as professional development or as preservice teachers) and “When Working With Students” (i.e., in grades 5–12 classrooms). The sample inquiry questions typically include attention to “big picture” unifying concepts or themes (drawn from the National Science Education Standards [NRC 1996] and the Benchmarks for Science Literacy [AAAS 1993]) that guide the learners to use empirical evidence, logical argument, and skeptical review to make and revise hypotheses about what is occurring and why. Meaningful learning occurs when teachers build on knowledge- and comprehension-type questions (e.g., What do you observe?) up to questions that require higher-order thinking skills associated with application, analysis, synthesis, and evaluation (e.g., How do you account for and apply the science underlying your observations?) (Anderson and Krathwohl 2001; Bloom et al. 1956).

The sample inquiry questions in this section and the Debriefing section are not intended to be used verbatim; rather, they suggest possible productive lines of inquiry and model the art of effective science questioning. Effective questioning that elicits quality responses is not easy. In addition to optimal wait time, it requires a solid understanding of subject matter, attentive consideration of each student’s remarks, as well as skillful crafting of further leading questions. (NRC 2001b, p. 35)

Questions posed by the teacher serve multiple pedagogical purposes. They catalyze two-way teacher-student interactions that go beyond a simple sequence of teacher question (initiation) → student response → teacher feedback that serve to “move a lesson along.” They also provide formative assessment to determine if students are “getting it” and the opportunity for clarifications and deeper probing of student conceptions. More important, teacher-initiated questions explicitly model for students how to ask their own scientifically productive questions that lead to fruitful, inquiry-based examination of phenomena by students and interactions among students. As such, the questions generated by students provide a window into their cognitive processing and evolving conceptions, perhaps even more so than their answers to teacher questions.

Additionally, student-initiated questions help students learn important metacognitive skills related to learning how to learn and to developing the
intellectual dispositions and habits of mind of active, engaged learners. Together, teacher- and student-initiated questions create a collaborative classroom environment based on a shared dialogue of discovery.

Debriefing
This section describes some of the broader context and lessons-to-be-learned about the science education and the science content. As in the Procedure section, separate “When Working With Teachers” comments (focused on science pedagogical knowledge) and “When Working With Students” comments (focused on science content) are provided as needed. The comments may also provide additional tips for teachers when using the activity to teach science to their grades 5–12 students. If desired, the teacher debriefing questions can be used as “homework” and/or discussed via electronic learning communities in live professional development sessions (NSTA 2008).

Extensions
These are brief descriptions of related “what if I were to change…” activities for further exploration as time and interest allow. Given the limited time in professional development settings, the extensions are especially useful for independent self-assessment work by teachers to determine if they really “get it.” The extensions also provide complementary activities that could be used to help design 5E Teaching Cycles or integrated instructional units for grades 5–12 science instruction (see Appendix B for a description of the 5E cycle). Also, when the science content connects with another activity in the book, the related activity is cited. The Extensions increase the number of distinct science inquiry activities in this book to nearly 120.

Internet Connections
In this list, readers will find up-to-date links to a variety of supplemental web-based resources including the following:

- Video clips of similar or related demonstrations where teachers can watch another teacher perform the mechanics of the demonstration
- Animations and interactive simulations that teachers can use to help the students visualize science principles and processes that are at scales that are too small/large, too fast/slow, or too dangerous or expensive to be seen with the unaided eye or realistically manipulated by students. Some of these websites (e.g., http://phet.colorado.edu) contain extensive libraries of simulations and related teaching materials that cut across science disciplines.
Introduction

• Online encyclopedias that further explain the science content and related real-world applications
• Short professional development readings related to the science education analogy

E-learning experiences and resources represent an ever-growing venue for teacher professional development and “just-in-time” instructional resources for teaching K–16 science (NSTA 2008). The internet is in a continual state of flux, but the majority of the cited web pages originate from relatively stable, nonprofit organizations (e.g., museums, professional associations, and universities). In addition to these websites, each of which has been reviewed by the author for relevance to the activities in this book, teachers may explore the science content and related curricular materials more broadly through NSTA SciLinks (www.scilinks.org).

In either case, occasional encounters with “dead” links are the equivalent of a book or journal going out-of-print or otherwise becoming unavailable—except that in the case of the internet, other great resources are always beckoning a few keystrokes away. As such, the sites provided should be viewed as starting points for further explorations. In addition to their inclusion in the book, an NSTA Press online, hyperlinked resource will allow readers to electronically access the sites in spring 2010.

Answers to Procedure and Debriefing Questions

The answers to the questions in the Procedure and Debriefing sections are deliberately presented at the very end of each activity. This was done to maintain the inquiry nature of the book. Attempting to answering the questions in the context of doing the activity (rather than reading the answers first) will help the teacher enjoy the activity more, appreciate the challenge that inquiry questions pose for his or her own students, and improve the teacher’s own questions and answers.

Conclusion

As teachers, we tend to teach both what and how we were taught during our “apprenticeships of observation” as K–16 students (Lortie 1975). It’s great to be able to stand on the shoulders of our own exemplary, former science teachers, but research on how to facilitate learning is always advancing. As such, this book challenges you to “question the answers” of your own past experiences as students and to make a paradigm shift away from any
pedagogical beliefs and practices that no longer make sense in the light of today’s research-informed standards.

The National Science Teachers Association has long recognized reflection-in-action by “teacher action-researchers… [as the] basis for curricular and instructional reform” (NSTA 1990; see also Schön 1983). The authors of the National Science Education Standards (NRC 1996) concur:

> The vision of science and how it is learned will be nearly impossible to convey to students in schools if the teachers themselves have never experienced it… preservice programs and professional development activities for practicing teachers must model good science teaching (p. 56).… Involve teachers in actively investigating phenomena that can be studied scientifically, interpreting results, and making sense of findings consistent with currently accepted scientific understanding (p. 59).… Teachers also must have opportunities to engage in analysis of the individual components of pedagogical content knowledge—science, learning, and pedagogy—and make connections between them. (p. 63)

This book’s combined science content—science education focus is designed to help current (or future) grades 5–12 science teachers, professional development specialists, and college-level science teacher educators achieve this standard.

The teacher is the key to change and learning in the classroom (NCMST 2000; NCTAF 1996, 1997; NSB 2006; NSTA 2007a). In fact, “the single most important factor affecting student academic gain is teacher effect” (Sanders and Rivers 1996). Some science teachers mistakenly believe that factors outside their control—such as family income, parent education levels, and race or ethnicity—are acceptable explanations for many of their students failing to learn science. On the contrary, effective teachers can cumulatively have a greater impact on educational outcomes than those factors (Ferguson and Ladd 1996). Specifically, the use of engaging activities in every science class is an example of something that is in the teacher’s control as is teacher collaboration in continuous professional development.

The book is the result of mutually beneficial interactions I have had with hundreds of dedicated science teachers over the last 30 years (e.g., O’Brien 1992a, 1992b; Stamp and O’Brien 2005; Stannard, O’Brien, and Telesca 1994). Please use, improve, and share these activities with your colleagues and students. I hope that you find this book to be “edu-taining” in ways that extend well beyond the initial surprise value and motivational impact of the individual activities. The best teaching and learning experiences are about sharing, catalyzing change in others, and being changed in the process.
Science Education Topics

This book has two focuses—science education and science concepts. The author has designed two alternative tables of content—in addition to the traditional one on pages v–vi—that are organized by these two focuses. The table of contents that begins on this page is organized by science education topics; the table of contents organized by science concepts begins on page 361.

Acronyms Used in Science Education Topics

BBS: Black Box System: A hidden mechanism is explored via observation and testable inferences.

BIO: Biological analogies and applications are specifically highlighted.

HOE: Hands-On Exploration: Learners working alone or in groups directly manipulate materials.

MIX: Mixer: Learners assemble themselves into small groups based on a specific task.

NOS: Nature Of Science: These activities focus on empirical evidence, logical argument, and skeptical review.

PAD: Participant-Assisted Demonstration: One or more learners physically assist the teacher.

POE: Predict-Observe-Explain: The activities use an inquiry-based instructional sequence.

PPP: Paper and Pencil Puzzle: The activities use a puzzle, which is typically focused on the NOS; often a BBS.

STS: Science-Technology-Society: The focus is on practical, real-world applications, and societal issues

TD: Teacher Demonstration: The teacher manipulates a system and asks and invites inquiry questions.

TOYS: Terrific Observations and Yearnings for Science: The activity uses a toy to teach science.
Section 1. Introduction to Interactive Teaching and Experiential Learning

<table>
<thead>
<tr>
<th>Activity</th>
<th>Activity Type</th>
<th>Science Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Analogies: Powerful Teaching-Learning Tools</td>
<td>MIX/PPP p. 3</td>
<td>analogies as conceptual tools (This is the only activity that is not a science discrepant event.)</td>
</tr>
<tr>
<td>2. Möbius Strip: Connecting Teaching and Learning</td>
<td>HOE/PPP p. 15</td>
<td>NOS, POE, topology</td>
</tr>
<tr>
<td>3. Burning a Candle at Both Ends: Classrooms as Complex Systems</td>
<td>TD p. 25</td>
<td>POE, phase change, combustion, convection, density, cellular respiration (Extension #3: BIO)</td>
</tr>
</tbody>
</table>

Section 2. Human Perception as a Window to Conceptions

<table>
<thead>
<tr>
<th>Activity</th>
<th>Activity Type</th>
<th>Science Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Perceptual Paradoxes: Multisensory Science and Measurement</td>
<td>PAD p. 37</td>
<td>sensory adaptations and survival (BIO), (mis)perception, cognition, temperature sensitivity, taste (as related to smell), weight versus density</td>
</tr>
<tr>
<td>5. Optical Illusions: Seeing and Cognitive Construction</td>
<td>PPP p. 47</td>
<td>sensory (mis)perception, cognition (BIO); quantitative measurements</td>
</tr>
<tr>
<td>6. Utensil Music: Teaching Sound Science</td>
<td>HOE p. 63</td>
<td>sound transmission, perception, sensory variations in species (BIO)</td>
</tr>
<tr>
<td>7. Identification Detectives: Sounds and Smells of Science</td>
<td>HOE/MIX p. 73</td>
<td>BBS, NOS, sensory adaptations, survival (BIO), identification by sound, identification by smell</td>
</tr>
</tbody>
</table>


Knowledge Transmission and Reception Versus Construction of Understanding

<table>
<thead>
<tr>
<th>Activity</th>
<th>Activity Type</th>
<th>Science Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Two-Balloon Balancing Act: Constructivist Teaching</td>
<td>HOE or PAD p. 87</td>
<td>NOS, POE, LaPlace’s law and surface tension, air pressure, BIOmedical applications (Extension #2)</td>
</tr>
<tr>
<td>9. Batteries and Bulbs: Teaching Is More Than Telling</td>
<td>HOE p. 97</td>
<td>complete or closed electric circuits, energy conversions</td>
</tr>
<tr>
<td>10. Talking Tapes: Beyond Hearing to Understanding</td>
<td>HOE p. 109</td>
<td>TOYS, sound, information encoding and gene expression, form/function relationships (BIO)</td>
</tr>
<tr>
<td>Activity</td>
<td>Activity Type</td>
<td>Science Concepts</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
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</tr>
<tr>
<td>Learning as a Psychologically Active, Inside-Out, and Outside-In Process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Super-Absorbent Polymers: Minds-on Learning and Brain “Growth”</td>
<td>HOE or PAD p. 119</td>
<td>measurement, polymers, TOYS, BIO/evolution, STS tradeoffs, perspiration (Extensions #2 and #4)</td>
</tr>
<tr>
<td>12. Mental Puzzles, Memory, and Mnemonics: Seeking Patterns</td>
<td>PPP p. 131</td>
<td>NOS, pattern recognition, cognition (BIO)</td>
</tr>
<tr>
<td><strong>Novelty and Changing Stimuli</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Sound Tube Toys: The Importance of Varying Stimuli</td>
<td>HOE or PAD p. 141</td>
<td>sound energy, pitch, Bernoulli’s principle, TOYS, POE, animal Bioadaptation of noticing novelty</td>
</tr>
<tr>
<td><strong>Puzzles and Discrepant or Counterintuitive Events</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Brain-Powered Lightbulb: Knowledge Transmission?</td>
<td>PAD p. 163</td>
<td>complete or closed electric circuit, Biofuels analogy (Extension #1), TOYS</td>
</tr>
<tr>
<td>16. Air Mass Matters: Creating a Need-to-Know</td>
<td>TD p. 171</td>
<td>air pressure, inertia, POE</td>
</tr>
<tr>
<td><strong>Cognitive Connections and Meaningfulness</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. 3D Magnetic Fields: Making Meaningful Connections</td>
<td>TD p. 179</td>
<td>magnetism, force field lines, neural networks, MRI (BIO/Extension #1)</td>
</tr>
<tr>
<td>18. Electric Generators: Connecting With Students</td>
<td>PAD p. 189</td>
<td>electric generators ↔ motors, electric circuits</td>
</tr>
<tr>
<td><strong>Multisensory Experiences and Multiple Contexts</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19. Static Electricity: Charging Up Two-by-Four Teaching</td>
<td>PAD p. 201</td>
<td>static electricity (triboelectricity)</td>
</tr>
<tr>
<td>20. Needle Through the Balloon: Skewering Misconceptions</td>
<td>HOE or PAD p. 211</td>
<td>polymer elasticity, cell membrane model (BIO/Extension #1)</td>
</tr>
<tr>
<td><strong>Emotional Engagement, Connections, and Relevance</strong>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21. Happy and Sad Bouncing Balls: Student Diversity Matters</td>
<td>HOE or PAD p. 221</td>
<td>TOYS, POE, potential→kinetic conversion, law of conservation of energy, friction, elasticity, form/function fitness (BIO)</td>
</tr>
</tbody>
</table>

*Each of the categories with an asterisk is one of the Seven Principles for Activating Attention and Catalyzing Cognitive Processing (Activities #13–#26). The seven principles have been identified by the author.
## Science Education Topics

(continued)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Activity Type</th>
<th>Science Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>22. Electrical Circuits: Promoting Learning Communities</td>
<td>HOE or PAD p. 233</td>
<td>complete or closed electric circuits, energy conversions, TOYS</td>
</tr>
</tbody>
</table>

### Adequate Time for Learning*

<table>
<thead>
<tr>
<th>Activity</th>
<th>Activity Type</th>
<th>Science Concepts</th>
</tr>
</thead>
</table>

### Psychological Rewards (Gain/Pain or Benefit/Cost Ratios)*

<table>
<thead>
<tr>
<th>Activity</th>
<th>Activity Type</th>
<th>Science Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>25. Optics and Mirrors: Challenging Learners’ Illusions</td>
<td>PAD p. 259</td>
<td>optical illusions, mirrors, BBS, NOS, TOYS</td>
</tr>
<tr>
<td>26. Polarizing Filters: Examining Our Conceptual Filters</td>
<td>TD p. 267</td>
<td>light polarization, UV protection for skin and eyes (BIO/Extension #1)</td>
</tr>
</tbody>
</table>

### Role of Prior Knowledge, Misconceptions, and Cognitive Inertia

<table>
<thead>
<tr>
<th>Activity</th>
<th>Activity Type</th>
<th>Science Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>27. Invisible Gases Matter: Knowledge Pours Poorly</td>
<td>PAD p. 275</td>
<td>gases occupy space (volume)</td>
</tr>
<tr>
<td>29. Rattlebacks: Prior Beliefs and Models for Eggciting Science</td>
<td>HOE or TD p. 293</td>
<td>BBS, NOS, TOYS, energy conversion, rotational inertia, model of the lithosphere</td>
</tr>
</tbody>
</table>

### Science Instruction Catalyzes Cognitive Construction

<table>
<thead>
<tr>
<th>Activity</th>
<th>Activity Type</th>
<th>Science Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>30. Tornado in a Bottle: The Vortex of Teaching and Learning</td>
<td>PAD p. 301</td>
<td>gases occupy space, POE, TOYS</td>
</tr>
<tr>
<td>31. Floating and Sinking: Raising FUNDaMENTAL Questions</td>
<td>HOE p. 309</td>
<td>density/buoyancy, diffusion, osmosis (BIO), nucleation sites, solubility of gases in liquids, NOS, POE</td>
</tr>
<tr>
<td>32. Cartesian Diver: A Transparent But Deceptive “Black Box”</td>
<td>HOE p. 321</td>
<td>Archimedes and Pascal’s principles, Boyle’s law, density/buoyancy, BBS, NOS</td>
</tr>
<tr>
<td>33. Crystal Heat: Catalizing Cognitive Construction</td>
<td>TD/HOE p. 331</td>
<td>phase changes, latent heat, law of conservation of energy, BIO: cellular respiration (Extension #2), perspiration and thermoregulation (Extension #4), bee colony collapse disorder (Extension #5)</td>
</tr>
</tbody>
</table>

*Each of the categories with an asterisk is one of the Seven Principles for Activating Attention and Catalyzing Cognitive Processing (Activities #13–#26). The seven principles have been identified by the author.
Activity 16

Air Mass Matters: Creating a Need-to-Know

Expected Outcome
A flat pinewood stick (or other soft wood) is placed under several sheets of newspaper and extended over the edge of a table. It snaps when quickly struck, without lifting or tearing the paper.
Science Concepts

Air has weight and exerts a pressure of 10 N/cm$^2$ (or 14.7 lbs/in$^2$) at sea level. Gases are not “nothing.” Gases have mass, occupy space, exert pressure, and are composed of molecules separated by truly “empty” space. Inertia, or the tendency of a body at rest to stay at rest, is also a relevant factor in this experiment.

Science Education Concepts

Teachers sometimes need to initially take familiar (and therefore unnoticed) things and make them strange so that they can become familiar again but—the second time around—understandable. Discrepant or counterintuitive events activate learners’ attention and catalyze cognitive processing by creating need-to-know motivation. This demonstration serves as a visual participatory analogy in the sense that students/sticks can only successfully lift the conceptual weight or load of a given educational task if the instructional pace (or speed) that they are expected to move at is within their zone of proximal development or ZPD (i.e., what the learner can achieve based on prior knowledge and abilities with the scaffolding provided by a carefully targeted instructional sequence and a supportive teacher). In the case of this demonstration, if the teacher pushes the student/stick at a too fast a rate, it breaks. If the teacher wants to avoid breaking the student/stick, he or she needs to use a slow, deliberative pace rather than a forceful, quick pass through too many topics in too little time (see Internet Connections: Wikipedia: Cognitive load theory and ZPD).

Materials

- Flat pinewood stick (e.g., cheap yardstick or extra long [2 ft.] paint stick) and several sheets of newspaper

Safety Note

Students and teacher should wear safety glasses or goggles during this activity.
Points to Ponder

I do not mind if you think slowly. But I do object when you publish more quickly than you think.
—Wolfgang Pauli, German-American physicist (1900–1958)

When you believe you have found an important scientific fact, and are feverishly curious to publish it, constrain yourself for days, weeks, years sometimes, fight yourself, try and ruin your experiments, and only proclaim your discovery after having exhausted all contrary hypotheses.
—Louis Pasteur, French chemist and microbiologist (1822–1895)

Procedure

(See answers to questions in steps #1–#4 on p. 177.)

1. Place the pine wood stick on a table with about 10 cm (4 in.) extending over the edge. Ask: What would happen if I were to strike the extended end of the wood? Do this experiment.

2. Repeat the experiment, except this time place two, full sheets of standard-size newspaper on top of the portion of the wood stick that rests on the tabletop, taking care to smooth out the newspaper and press it down firmly against the tabletop. If this is not done and a significant air pocket resides under the paper, the demonstration will not work consistently as intended due to an equalization of air pressure above and below the paper. Again, ask the learner to predict what will happen when you rapidly strike the extended portion of the stick.
3. Ask questions such as the following:
   a. What did you observe in this second case and how can you explain the difference between these two trials?
   b. What would happen if I placed the wood stick on the table without the newspaper and had someone press down on the portion that rests on the table while I strike the extended portion?
   c. What would happen if I used the newspaper again, but rather than striking the stick, I slowly pressed down on it?
   d. How do these extra tests provide clues as to how to explain the demonstration in which the stick breaks?

   Any of these variations can be repeated with new sticks (or by extending the stick if it is long enough).

4. Depending on where this activity is used in a 5E science unit (i.e., Engage versus Explain or Elaborate; see Appendix B for a discussion of the 5E Teaching Cycle) and the grade level, the teacher may have students calculate the effective weight of air that is pressing down on the surface area of a single piece of newspaper.

Debriefing
When Working With Teachers
In a discrepant-event demonstration, the teacher takes something that is typically unnoticed by students (e.g., air pressure) and makes them pause, perceive anew, and ponder on this thing (i.e., it activates their attention). Discuss the pedagogical advantages of using the phenomena-before-facts or the wow-and-wonder-before-words approach over the common (reverse) approach in which the teacher starts with lecture notes or gives a reading assignment on air pressure. Teachers can explore the large body of published research on student misconceptions about gases, air, and pressure (e.g., see Driver et al. 1994; see chapters 9 and 13 for overviews).

The demonstration serves as a visual participatory analogy for how the cognitive load of a given educational task or learning objective—as perceived by students—depends, in part, on the speed of instruction. Rushing through big ideas too quickly can “break”
students, whereas a slower, more deliberate approach is much more likely to succeed. The contrasting quotes on page 173 can focus learners’ attention on the nature of science (i.e., empirical evidence, logical argument, and skeptical review) and can help them contrast the relative checks on truth in the popular press versus such checks on scientific journals.

The best science teaching is more about inspiring inquiry than indoctrination in “received truth.” Similarly, if students are going to be asked to calculate the weight of air pressing down on the paper, it is important that the teacher first create a context that catalyzes learners’ curiosity—rather than present calculations in no context at all, an approach that will kill curiosity.

When Working With Students
After students do other related activities—such as the Extensions and activities found on websites listed in Internet Connections—that make the unnoticed effect of air pressure “sensible,” the teacher should introduce the basic facts about air pressure discussed in the Answers to Questions in Procedure, step #3 on p. 177.)

Extensions

1. *The Crushing Soda “Pop” Can.* This discrepant event is a variation of an old demonstration. A little water placed in an empty 1 gal. rectangular metal can is brought to a boil and the can is then removed from the heat and tightly capped. As the can cools, the water vapor condenses and leaves a partial vacuum inside the sealed can that then collapses under the now greater, external atmospheric pressure. With a soda can, just cover the bottom of the empty can with water, boil it to drive out air, and fill the can with water vapor. Then either cap the can with a fizz-saver lid or turn the can upside-down on top of a container of water. In the latter case, the can will rapidly crush and partially fill with water. (See Internet Connections: Purdue University, among other websites, for explanations.)

Alternatively, a vacuum pump causes the reverse expansion effect by decreasing external pressure on a partially sealed, air-filled container (e.g., a balloon, a marshmallow, or shaving cream) that is under an evacuated, airtight chamber.

**Safety Note**

The edges of metal cans can be sharp and can cut the skin. Handle with caution.
2. Air Mass Matters. Place two identical, uninflated balloons on a double-pan balance. (See safety issues regarding latex balloons on p. 89. Avoid latex balloons.) They will balance. If one of the balloons is then inflated and tied off, the balance will tip in direction of that balloon, indicating that air has mass. Similarly, a teacher can demonstrate that if a deflated sports ball is weighed and subsequently pumped up with air, the mass gain is directly proportional to the number of pumps. Alternatively, this can be done on a smaller scale as a hands-on exploration by using fizz-saver caps and a 2 L empty soda bottle. (Note: P1-2050/Individual Pressure Pumper can be purchased from Arbor Scientific for $3.25 or from local stores as a device to save the fizz on opened soda bottles). In either case, you may want to use temperature strips on the plastic bottle to also study the relationship between pressure and temperature.

Internet Connections

- Arbor Scientific’s Cool Stuff Newsletter: www.arborsci.com/CoolStuff/Archives3.aspx. (See Chemistry: Gas laws smorgasbog and Pressure and fluids demonstrations.)
- Can Crush Demo/Railroad Tank Car Crush: www.delta.edu/slime/cancrush.html
- HyperPhysics, Department of Physics and Astronomy, Georgia State University: Select Video/Demos: Fluids: Liquids and gases: Atmospheric pressure: http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html
- Purdue University: Can crusher: http://chemed.chem.purdue.edu/genchem/demosheets/4.8.html
- University of Iowa Physics and Astronomy Lecture Demos. http://faraday.physics.uiowa.edu (See Heat and fluid: Atmospheric pressure demonstrations: Crush the can, crush the soda can; Magdeburg hemispheres; Water column-water barometer; Suction cups-rubber sheets; Stick and newspaper and the vacuum cannon.)
- University of Virginia Phun Physics Show: http://phun.physics.virginia.edu/demos (See Bell jar/shaving cream in vacuum; Collapsing drum; Magdeburg hemispheres; Marshmallow man.)

• Whelmers #21 Balloon (in Bottle) Vacuum: www.mcrel.org/whelmers/whelm21.asp


Answers to Questions in Procedure, steps #1–#4

1. The wood flips in a somersaulting motion just as most people would predict.

2. A likely response will be that the stick will again fly up but that this time the stick will either take the paper with it or rip the paper.

3. When the newspaper is placed over the wood, the wood breaks right at the edge of the table if the demonstrator strikes hard rather than slowly pressing down on the wood. In the latter case, the newspaper is lifted up. By smoothing the paper firmly against the table and removing air from underneath, you create a situation where the wood sticking up is pushing against the weight of a column of air that extends to the outer limits of the Earth’s atmosphere. Inertia causes the paper to remain at rest and the rapidly moving end of the stick to keep moving, which it does by snapping at the point where it extends just beyond the table. Conversely, if the wood stick is pushed down slowly, the air that seeps in underneath the paper can exert pressure upward to counterbalance the air pressure on top of the paper and the stick can easily lift the paper up without snapping. The relevant explanatory facts are as follows: air pressure = force/area = weight of the column of air/surface area. At sea level, air pressure = 10 newtons/cm² or 14.7 lbs/in². (Note: 10 N = weight of a 1 kg mass at sea level.)

4. The calculation of the effective weight of the column of air that is pressing down on the surface area of a single piece of newspaper is as follows: surface area = 61 cm × 53 cm = 3,233 cm² and weight = 3,233 cm² × 1 kg/cm² = 3,233 kg (technically, kg is a unit of mass, not weight) or nearly 7,113 lbs!
index

A
Access Excellence, 218, 290
accommodation, 120
Adler, Mortimer, 6
air and air pressure
“air mass matters” activity, 171–177
“identification detectives” activity, 73–83
“invisible gases matter” activity, 275–283
“sound tube toys” activity, 141–151
“tornado in a bottle” activity, 301–307
“two-balloon balancing act” activity, 87–96
“air mass matters” activity, 171–177
debriefing in, 174–175
extensions for, 175–176
internet connections for, 176–177
materials for, 172
procedure in, 173–174
science concepts in, 172
All About Electricity, 106, 239
Amateur Science, 195
ambigrams, 21–22
ambiguous figures, 48–49, 53–54
American Educator, 69, 81, 137, 207, 263
on buoyancy, 316
on gas laws, 282
on inertia, 256
on membranes, 218
analogies, 3–15, xv
auditory participatory, 63–71
“magnetic fields,” 179–188
“sound tubes,” 141–151
biological cell membrane, 217
debriefing with, 9–10
extensions of, 12
internet connections for, 12–13
materials for, 5
as mental models, 4
points to ponder with, 6
procedure with, 7–9
sample, 11
selection criteria for, 343–353
visual participatory, xi–xii
“air mass matters,” 171–177
“batteries and bulbs,” 97–108
brain growth and, 119–129
“brain-powered lightbulb,” 163–170
“burning a candle at both ends,” 25–33
“Cartesian diver,” 321–329
“convection” activity and, 153–162
“crystal heat,” 331–342
“eddy currents,” 241–249
“floating and sinking,” 309–320
“happy and sad bouncing balls,” 222–231
“invisible gases matter,” 275–283
“learning communities” activity, 233–240
“magnetic fields” and, 179–188
Möbius strip, 15–23
“needle through the balloon,” 211–219
optical illusions as, 51–61
“optics and mirrors,” 259–265
“polarizing filters,” 267–273
“rattlebacks,” 293–299
of sound energy, 73–83
sound tubes and, 141–151
tornado in a bottle,” 301–307
“two-balloon balancing act,” 87–96
anamorphoses proper, 49, 55
Annenberg Foundation, 106
Antisthenes, 277
Arbor Scientific’s Cool Stuff Newsletter, 69, 106, 115, 148, 169, 176
on Cartesian divers, 328
on eddy currents, 247
on electrical circuits, 239
on electric generators, 195
on gas laws, 282, 317
on inertia, 256, 298
on magnetism, 187
on polarization, 272
on pressure and fluids, 306
on static electricity, 207
Archimedes’ Laboratory, 59
Aristotle, 277, 303, 304
Asimov, Isaac, 4, 65
assessment, 355–360
assimilation, 120
assumptions, challenging, 304
Athabasca University Centre for Psychology Resources, 43, 59
attributes, shared, 4–5
audiology careers, 69
auditory participatory analogies. See analogies
Austine Studios Polarized Light Art, 272
Ausubel, David, 288
Index

B
Bacon, Francis, 244, 295
Bacon, Roger, 261
balloons
   in “air mass matters,” 176
   in a bottle, 280–281
   hot air, 158, 159
   “needle through the balloon” activity, 211–219
   static electricity and, 201–209
   “two-balloon balancing act,” 87–96
banking analogy of learning, 259–265
BASF Superabsorbent Polymer
   Hygiene and Industrial Applications, 127
“batteries and bulbs,” 97–108
   debriefing in, 102–105
   extensions for, 105–106
   internet connections with, 106–107
   materials for, 99
   procedure for, 100–102
   science concepts in, 98
Becker Demonstrations, 159, 229, 282, 328
Bell, Alexander Graham, 65, 75, 80, 112
Benchmarks for Science Literacy, xx
   on “less is more” approach, 43
   on toys and engagement, 142
Ben Dosa, Hanina, 28
Bernoulli’s principle, 147
Bernoulli’s Principle Animation, 148
bio-energy, 168
biological applications/analogies
   “brain-powered lightbulb” activity, 163–170
   “burning a candle at both ends” activity, 25–33
   “crystal heat” activity, 331–342
   “floating and sinking” activity, 309–320
   “happy and sad bouncing balls” activity, 228
   “identification detectives” activity, 73–83
   “magnetic fields” activity, 179–188
   “mental puzzles, memory, mnemonics” activity, 131–140
   “needle through the balloon” activity, 211–219
   optical illusions, 21, 47–61
   perceptual paradoxes activities, 37–46
   “polarizing filters” activity, 267–273
   “sound tube toys” activity, 141–151
   “super-absorbent polymers” activity, 119–129
   “talking tapes,” 109–117
   “two-balloon balancing act,” 87–96
   “utensil music” activity, 63–71
   biological cell membrane analogy, 217
   Biological Sciences Curriculum Study (BSCS), 356
   Bizarre Stuff You Can Make in Your Kitchen, 339
   black box experiments, 73–83
   “Cartesian diver,” 321–329
   happy/sad balls, 228
   Bloomfield, Louis A., 186
   Bloom’s Taxonomy, 247, 248
   Boyle, Robert, 322
   Boyle’s law, 322
   brain growth, 119–129
   “brain-powered lightbulb” activity, 163–170
   debriefing in, 167–168
   extensions for, 168–169
   internet connections for, 169
   materials for, 164–165
   procedure for, 166–167
   science concepts in, 164
   brainstorming vs. brainwashing, 92
Brigham Young University Physics
   Computer Resources, 272
Brilliant, Ashleigh, 183
Brue, John T., 213, 218
Bruner, Jerome, 6
Bubbles, Babies and Biology, 94
buoyancy, 309–320
“burning a candle at both ends” activity, 25–33
   debriefing in, 29–31
   extensions for, 31–32
   internet connections for, 33
   materials for, 27
   procedure in, 28–29
   science concepts in, 27–28
C
Can Crush Demo, 176
   cans, crushing, 175
   “Cartesian diver,” 321–329
   debriefing in, 325
   extensions for, 326–327
   internet connections for, 328–329
   materials for, 322–323
   procedure for, 323–324
   science concepts in, 322
CAST, 44, 229
catalysis, 331–342
change
   “happy and sad bouncing balls” and, 222–231
   law of, 206
   resistance to, 252
   Changing Minds, 247
   Chesterton, G. K., 155
   Clarke, Arthur C., 21
cognition, xvi–xvii
   batteries and bulbs, 97–108
   brain growth and, 119–129
   “brain-powered lightbulb” and, 163–170
   challenging learners’ illusions in, 259–265
   “cognitive inertia” activity, 251–258
   conceptual filters and, 267–273
   “convocation” activity and, 153–162
“eddy currents” activity and, 241–249
“electric generators” activity and, 189–199
“happy and sad bouncing balls” activity and, 221–232
“knowledge pours poorly,” 275–283
“learning communities” activity, 233–240
“magnetic fields” activity and, 179–188
mental puzzles, memory, mnemonics and, 131–140
“needle through the balloon” activity and, 211–219
need-to-know and, 171–177
sound tubes and, 141–151
“static electricity” activity and, 201–209
talking tapes,” 109–117
two-balloon balancing act, 87–96
cognitive connections, xvii
cognitive construction, 193–194, xvi, xvii
“Cartesian diver” and, 321–329
catalyzing, 331–342
cognitive disequilibrium, xi
cognitive inertia, xvii
“cognitive inertia” activity, 251–258
debriefing in, 255–256
extensions for, 256
internet connections for, 256–257
materials for, 252
procedure for, 253–255
science concepts in, 252
cognitive learning theory, xvi–xvii
Coke eruption, 315–316
colors, Stroop Effect in, 285–291
concept maps, 180–181, 185
conceptual change teaching
“cognitive inertia” activity and, 251–258
“convection” activity and, 153–162
“conceptual filters” activity, 267–273
conceptual survival, 289
Concord Consortium, 207, 317, 339
conservation. See recycling and conservation
conservation of energy
“crystal heat” activity, 331–342
“happy and sad bouncing balls” activity, 221–232
conservatism. See cognitive inertia
constancy, “happy and sad bouncing balls” and, 222–231
constructivism, 282
“electric generators” activity and, 189–199
“optics and mirrors” and, 259–265
Constructivism and Learning Theories, 306
contexts, multiple, 212, xvii
“convection” activity, 153–162
debriefing in, 157–158
extensions for, 158
internet connections for, 159–160
materials for, 154
procedure for, 155–156
science concepts in, 153–162
Cooperative Learning Center, University of Minnesota, 239
creativity, cognition and, 169
“crystal heat” activity, 331–342
debriefing in, 336–337
extensions for, 337–339
internet connections for, 339–340
materials for, 333–334
procedure for, 334–336
science concepts in, 332–333
curriculum design, 355–360

D

Dallas Symphony Orchestra, 69
Dalton, John, 303
Darwin, Charles, 39
da Vinci, Leonardo, 277
Davy, Humphrey, 32
Death, Money, and the History of the Electric Chair, 196
density
“burning a candle at both ends” activity, 25–33
“Cartesian diver,” 321–329
“convection” activity, 153–162
“floating and sinking” activity, 309–320
“multisensory science and measurement” activity, 37–46
Descartes, Rene, 322
Dewey, John, 17, 133, 143, 213, 261, 262, 323
diapers, disposable, 125, 127
diffusion, 309–320
Dilated Cardiomyopathy, 94
discrepant-event activities, xi, xvii
“air mass matters,” 171–177
analogies and, xii
“brain-powered lightbulb,” 163–170
challenging misconceptions with, 212
compare/contrast, 154
“convection” activity, 153–162
“learning communities” activity, 233–240
Möbius strip, 15–23
“needle through a balloon,” 211–219
selection criteria for, 343–353
sound tube toys, 141–151
“static electricity” activity, 201–209
diversity
“happy and sad bouncing balls,” 221–232
Diving Insect Regulates Buoyancy, 317, 328
Doing Chemistry, 81, 159, 340
Doing CL, 239
“Double Trouble with Bubbles,” 93
Index

Dropper Popper toy, 228–229
dry ice, 337–338
Duit, R., 290, 299

E
economy, 346–347
“eddy currents” activity, 241–249
debriefing in, 246
extensions for, 247
internet extensions for, 247–248
materials for, 243
procedure for, 244–246
science concepts in, 242–243
Edible Candle, 31–32
Edison, Thomas Alva, 75, 80–81, 110, 112, 191, 194–195
education concepts, 4–5
Education Trust, 18–19
effectiveness, 348–352
egg experiments, 297–298
Einstein, Albert, 165, 203, 224, 235, 323
Elaborate phase, 359
e-learning, xxii
“electrical circuits: promoting learning communities” activity, 233–240
debriefing in, 237–238
extensions, 238–239
internet connections for, 239–240
materials for, 235
procedure for, 236–237
science concepts in, 234–235
“electric generators” activity, 189–199
debriefing in, 193–195
extensions for, 195
internet connections for, 195–196
materials for, 191
procedure for, 192–193
science concepts in, 190
electricity
“batteries and bulbs,” 97–108
“brain-powered lightbulb,” 163–170
“eddy currents” and, 241–249
“electric generators” activity, 189–199
static, 201–209
Electronics for Kids, 106
emergent properties, 16
emotional engagement, xvii
“Empty the Bottle Race,” 280
Encyclopedia of Science, 298
energy. See conservation of energy
Energy Balls, 233–240
engagement
in 5E Teaching Cycle, 356–357
fun first for, 74, 78
learning communities and, 233–240
in “two-balloon balancing act,” 92
varying stimuli and, 141–151
enjoyable activities, 346–347
Escher, M.C., 12, 19, 20, 22, 60
ethics, “happy and sad bouncing balls” and, 221–232
Evaluate phase, 359–360
evidence, “happy and sad bouncing balls” and, 222–231
evolution
brain, 120, 234
“happy and sad bouncing balls” and, 222, 228
of human senses, 39, 41, 45, 74, 79
novelty and, 142, 150, 151, 157
Explain phase, 358–359
Exploratorium, 59, 94, 138, 159
on Cartesian diver, 328
on tornado in a bottle, 306
Exploratorium Online
on eddy currents, 247
on magnetism, 187
on motors, 196
on polarization, 272
on static electricity, 207
Exploratorium Snacks, 44
Exploratory Science Centre, 59
Explore phase, 357–358
eyedropper divers, 321–329
Eyetricks.com, 59

F
Faraday, Michael, 32, 180, 242, 244
“Fill That Bottle Race,” 280
fire. See “burning a candle at both ends” activity
5E Teaching Cycle, 355–360
Flash Animations for Physics, 106, 239
“floating and sinking” activity, 309–320
debriefing in, 314–315
extensions for, 315–316
internet connections for, 316–317
materials for, 311
procedure for, 312–314
science concepts in, 310
Flubber (movie), 229
“Fortune Teller Miracle Fish” activity, 126
Franklin, Benjamin, 207
friction, 226
“rattlebacks” and, 293–299
fruits, floating, 316
fun, engagement via, 74, 78, 202
“floating and sinking” activity, 309–320
Stroop Effect and, 285–291

G
Galilei, Galileo, 122, 225, 253
Gardner, Martin, 21, 33
gas laws, 95–96
air mass and, 171–177
“invisible gases matter,” 275–283
kinetic molecular theory, 211–219
“tornado in a bottle” and, 301–307
genetics, 114–115
 genie in a bottle, 340
Gestalt psychology, 50–51, 59, 183–184
Goethe, Johann Wolfgang von, 269
Gould, Stephen Jay, 4
gravity
gravitational potential, 225, 226
“rattlebacks” and, 293–299
Haldane, John, 90
hands-on explorations (HOEs), 55, 104, 110, 123, xv
hand warmers, 338–339
“happy and sad bouncing balls” activity, 221–232
debriefing in, 227–228
extensions for, 228–229
internet connections for, 229–230
materials for, 223
procedure for, 224–227
science concepts in, 74
Illusions-Optical.com, 60, 230
Illusion Works, 60, 263
implementation dip, 268
Indestructables, 187
inertia, 172. See also motion, laws of
“air mass matters” activity, 171–177
debriefing in, 78
extensions for, 78–81
internet connections with, 81–82
materials for, 74–75
procedure for, 76–77
science concepts in, 74
Hawking, Stephen, 4
Hering, Joseph, 242
Hightet, Gilbert, 17
history and philosophy of science (HPS), xix
History Guide, The, 44
HomeHarvest Garden Supply’s Soil Moist, 127
hot air balloons, 158, 159
Howard Hughes Medical Institute, 44, 60
How Everything Works: Making Physics Out of the Ordinary (Bloomfield), 186
HowStuffWorks, 33, 44, 69, 106, 115
on convection, 159
on disposable diapers, 127
on electricity, 196
on magnetism, 187
on memory, 138
on polarization, 272
on static electricity, 207

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for “talking tapes,” 115
for “tornado in a bottle,” 306
for “two-balloon balancing act,”
94
for “utensil music,” 69–70
inversions, 21–22
“invisible gases matter” activity,
275–283
debriefing in, 279–280
extensions for, 280–281
internet connections for, 282
materials for, 276
procedure for, 277–278
science concepts in, 276

J
James, Mark, 13
James, William, 133
Java Applets for Physics, 196, 317
just-in-time instruction, xxii

K
Katz, David, 218
Kettering, Charles F., 269
Kim, Scott, 21–22
Kind, V., 290, 299
kinetic energy, 226
kinetic molecular theory, 211–219
knowledge
“knowledge pours poorly”
activity, 275–283
prior (See prior knowledge)
transferability of, 304
transmission models, xvi
“knowledge pours poorly,” 275–283
Kuan-tzu, 6
Kuhn, Thomas, 58, 294

L
Lab-Aids Inc., 81
LaPlace’s law, 87–96, 94
lava lamps, 158
learners’ illusions, challenging,
259–265
learning
active, 110, 120, 259–265
analogies on, 3–15
banking analogy for, 259–265
catalysis in, 336–337
cognitive connections in,
179–188
conceptual density and, 314–315
empty vessel model in, 275–283
interactive, 309–320
“knowledge pours poorly,”
275–283
as listening, 98
meaning-making in, 58
mental puzzles and, 136–137
Möbius strip analogy of, 19–20
preconceptions in, 32
sample analogies on, 11
time required for, 241–249, xvii
vortex of teaching with, 301–307
Learning and Teaching Scotland, 69
Learning and Understanding Key
Concepts of Electricity, 106, 239
“learning communities” activity,
233–240
Lemelson Center for the Study of
Invention and Innovation,
106, 239
Lenz, Heinrich, 242
lesson plans, 190
Locke, John, 269
lung functioning, 94
Magz Magnetic Construction Toy,
187
mapping, analogies and, 4–5
Marcus Aurelius, 90
Mathematical Genealogy Project,
22
“Mathematical Measurement
Merriment,” 93
Math Forum, 22
Meaningful Learning Research
Group, 299
meaningfulness, xvii
optical illusions and, 58
perceptual paradoxes and, 38
measurement
“floating and sinking” activity,
309–320
“happy and sad bouncing balls”
and, 222–231
optical illusions and, 21, 47–61
“super-absorbent polymers”
activity, 119–129
memory, 131–140
musical, 186
“mental puzzles, memory,
mnemonics” activity, 131–140
debriefing in, 136–137
extensions for, 137
internet connections for,
137–138
materials for, 133
procedure for, 134–136
science concepts in, 132
mentors, for teachers, xiv
Mentos geyser, 315–316
“Milk Bottle Magic,” 216–217
“Minds-On Mnemonics” activity,
126–127
misconceptions, 32. See also prior
knowledge
about collaboration, 237–238
about electricity, 193–194
bigger is better, 87–96
“convection” activity and,
153–162
“needle through the balloon”
activity and, 211–219
pedagogical implications of, 279
perceptual, 38
“rattlebacks” and, 293–299
mixer activities, 3
“identification detectives,” 73–83
mnemonics, 126–127, 131–140
musical memory as, 186
Möbius, Augustus Ferdinand, 20
Möbius strip activity, 15–23
debriefing in, 18–20
extensions of, 20–22
internet connections with, 22
materials for, 16–17
procedure for, 18
Molecular Expressions, 247
momentum, 228. See also motion, laws of
Morse, Samuel, 112
MOSART, 290
motion, laws of, 251–257
“rattlebacks” and, 293–299
multisensory experiences, 205, xvii
“needle through the balloon,” 211–219
“multisensory science and measurement” activity, 37–46
debriefing in, 42–43
extensions with, 43
internet connections for, 43–44
materials for, 38–39
procedure for, 39–41
science concepts in, 38
on taste and smell, 41, 43
on thermal energy, 40, 42
on weight, 41, 43
musical memory, 186
Music Through the Curriculum, 148
Mystery of Smell, 81

N
Nanopedia, 94, 218
NASA, 33, 159
National Association for Research in Science Teaching (NARST), 159, 256
National Human Genome Research Institute, 115
National Science Education Standards, 19, xx, xxiii
on “less is more” approach, 43
selection criteria based on, 343–353
on toys and engagement, 142
National Science Teachers Association, xxiii
nature of science (NOS) mental puzzles and, 131–140
Möbius strips and, 16
“rattlebacks” and, 293–299
“needle through the balloon” activity, 211–219
debriefing in, 215–216
extensions for, 216–218
internet connections for, 218
materials for, 212–213
procedure for, 214–215
science concepts in, 212
need-to-know, 171–177
“eddy currents” and, 246
Neural Networks, 187
neural networks, 181
Neuroscience for Kids, 60, 81, 187
Newton, Isaac, 235, 253
laws of motion, 251–257
Nexus Research Group, 196
Nondestructive Testing Resource Center, 81, 247
North Carolina Science Teachers Association, 257
Northwestern University, 12
NOS. See nature of science (NOS)
NOVA Online, 81
novelty, xvii
“convection” activity and, 153–162
evolution and, 142, 150, 151, 157
number sequences, memorizing, 134–135

O
“Odoriferous Olfactory
Observations,” 78–79
Operation Physics, 291
optical illusions, 21, 47–61
ambiguous figures, 48–49, 53–54
anamorphoses proper, 49, 55
debriefing with, 59
internet connections for, 59–60
materials for, 51–52
perceptual set, 49–50, 55–56
procedure for, 53–58
science concepts in, 48–51
shape/linear size distortion, 50, 56–57
optics and mirrors, 259–265
polarizing filters and, 267–273
“optics and mirrors” activity
debriefing in, 259–265, 262–263
extensions for, 263
internet connections for, 263–264
materials for, 260
procedure for, 261–262
science concepts in, 260
osmosis, 309–320

P
panpipes, 147
paradigm shifts, 58
paradoxes, perceptual, 37–46
optical illusions, 47–61
in smells, 73–83
sound science, 63–71
pareidolia, 50
Pascal, Blaise, 322
passive reception models, xvi
Pasteur, Louis, 173
Pauling, Linus, 90, 183
Pauli, Wolfgang, 173
Pavlov, Ivan, 143
PBS Teachers Resource Roundups, 247
Penny for Your Thoughts, 43
perceptions, xvii
as antecedents to mental conceptions, 74
hearing, 63–71
Index

multisensory science and measurement and, 37–46
novelty and, 153–162
optical illusions and, 47–61
paradoxes in, 37–46
smells, 73–83
sound, 63–71, 73–83
perceptual set optical illusions, 49–50, 55–56
performance pressure, 325
perspiration, 339
phase changes
“burning a candle at both ends” activity, 25–33
“crystal heat,” 331–342

PhET Interactive Simulations, 69,
106, 148, 159, 187, 196, 340
on eddy currents, 247
on electrical circuits, 239
on static electricity, 207
Philomel Records, 69
Philosophical Toy, 328
Pickover, Clifford, 21
pitch (sound), 141–151
Planet Perplex, 22, 60
POE. See predict-observe-explain (POE)
Poe, Edgar Allen, 27
Poincaré, Jules Henri, 183
“polarizing filters” activity, 267–273
debriefing in, 270–272
internet connections for, 272
materials for, 268–269
procedure for, 270
science concepts in, 268
polymers
“happy and sad bouncing balls” activity, 221–232
“needle through the balloon” activity, 211–219
“super-absorbent polymers” activity, 119–129
preconceptions, 32. See also prior knowledge
“polarizing filters” and, 267–273
predict-observe-explain (POE), 16, xv
in “burning a candle at both ends,” 25–33
preservice science methods courses, xiii
prior knowledge, xvii
analogies in activating, 4–5
in “burning a candle at both ends,” 27
misconceptions in, 294–299
“needle through a balloon” and, 211–219
novelty and, 153–162
optical illusions and, 58
“rattlebacks” and, 293–299
“Stroop Effect” and, 285–291
in “two-balloon balancing act,” 92
professional development, xiii–xviii

Q
Quality Trading.com, 60
questions and questioning, xx–xxi
allowing student, 202
answers to, xxii
in “brain-powered lightbulb,” 168
“raising FUNdamental,” 309–320
wait time in, 242–243

R
Railroad Tank Car Crush, 176
“rattlebacks” activity, 293–299
debriefing in, 297
extensions for, 297–298
internet connections for, 298–299
materials for, 295
procedure for, 296
science concepts in, 294
recycling and conservation
“batteries and bulbs,” 97–108
“super-absorbent polymers” activity, 119–129
reflection-in-action, xxi
on Möbius strips, 21
Reframing the Mind, 44, 230
relevance, 352–353, xvii
learning communities and, 233–240
rewards, psychological, 262, xvii
Robertson, Frederick W., 28
Rogers, Will, 269
Royal Institution of Great Britain, 187

S
safety, 344–345
Sagan, Carl, 4
Sandlot Science, 60
scaffolds, xii
analogies as, 4–5
“happy/sad balls” and, 223
mental puzzles and, 136–137
Science and Technology Center for Environmentally Responsible Solvents and Processes, 127
Science Hobbyist, 218, 299
Science Odyssey, 107, 239
Science Project, 196
Science Spot, 127
scientific method, 310
selective attention theory, 285–291
senses, xvi
shape/linear size distortion illusions, 50, 56–57
Shaw, George Bernard, 52
Shulman, Lee, 224
signal-to-noise ratios, 78
Silly Cylinders, 43
simplicity, 345–346
Skeptic’s Dictionary, 60
Slinkies, 147
Snopes.com, 196
Society for Neuroscience, 44, 81, 169, 187
sound perceptions
“identification detectives” activity, 73–83
sound tubes and, 141–151
“talking tapes,” 109–117
“utensil music,” 63–71
“sound tube toys” activity, 141–151
debriefing in, 145–146
extensions for, 147
internet connections for, 148
materials for, 142–143
procedure in, 143–145
science concepts in, 142
Spangler, Steve, 127, 305
“static electricity” activity, 201–209
debriefing in, 205–206
extensions for, 206–207
internet connections for, 207–208
materials for, 202
procedure for, 203–205
science concepts in, 202
stimuli, changing, 141–151, xvii
“Straw Symphony,” 147
debriefing in, 289
extensions for, 290
internet connections for, 290–291
materials for, 287
procedure for, 287–289
science concepts in, 286–287
sublimation, 337–338
submarines, soy sauce, 326
Success for All Foundation, 239
“super-absorbent polymers” activity, 119–129
debriefing in, 124
extensions for, 124–127
internet connections for, 127
materials for, 120–121
procedure for, 122–124
science concepts in, 120
supersaturation, 339
Surfing Scientist, 107, 239, 306
sweating, 339
synergy, 183–184
systems, complex, 25–33

ds
“talking tapes,” 109–117
debriefing in, 114
extensions for, 115
internet connections for, 115
materials for, 111
procedure in, 112–114
science concepts in, 110
teachable moments, 285
teachers
as action-researchers, xxiii
effective, xxiii
as gardeners, 13–14
as learner-experimenters, xii
mentoring for, xiv
professional development for, xiii–xiv
self-reflection by, 3
teaching
catalysis in, 336–337
cognitive connections in, 189–199
collaborative, 234–235, 237–238
critical thinking, 153–162
constructivist, 87–96
developmental level and, 26
5E Cycle of, 355–360
pedagogical approaches in, 205
predict-observe-explain approach to, 16, xv
sample analogies on, 11
sequencing in, 246
signal-to-noise ratio in, 78
social interactions in, 189–199
as telling, 98
vortext of learning with, 301–307
Teaching Teachers to Use Analogies, 13
Teaching With Analogies Model, 13
Termite Trails, 306
Terrific Science, 33
thermal energy, 40, 42
thermoregulation, 339
Thomas, Lewis, 4
Thorndike, Edward L., 288
Tin Can Telephones, 67–68
topology, 16
tornado in a bottle,” 301–307
debriefing in, 304–305
extensions for, 305
internet connections for, 306
materials for, 302–303
procedure for, 303–304
science concepts in, 302
TOYS. See terrific observations and yearnings for science (TOYS)
Toys in Space II, 298
triangulation of understanding, xviii
Tulga, Phil, 148
Twain, Mark, 212
Twenty Brain Buster Q&A on Electrical Circuits, 169
two-balloon balancing act,” 87–96
debriefing in, 92–93
extensions for, 93
internet connections for, 94
materials for, 89
procedure for, 90–92
science concepts in, 88
Tyndall, John, 39
UCLA Reasoning Laboratory, 13
UFO Balls, 233–240, 238
ultraviolet radiation, 271
University of Colorado at Boulder, 60
University of Iowa Fluids Laboratory Image Gallery, 306
University of Iowa Physics and Astronomy Lecture Demonstrations, 33, 70, 159, 176
Index

on bouncing balls, 230
on density and buoyancy, 317
on eddy currents, 248
on electricity and magnetism, 196
on heat and fluids, 328
on inertia, 257
on mechanics, 298
on polarization, 272
on static electricity, 207
University of Minnesota, 340
University of Victoria, 248
University of Virginia Phun Physics Show, 208, 230
on inertia, 257
University of Virginia Physics Department, 44, 70, 107, 148, 160, 176, 188
on air properties, 282
on bouncing balls, 230
on eddy currents, 248
on electrical circuits, 239
on electromagnets, 196
on inertia, 257
on polarization, 272
on static electricity, 208
University of Wisconsin-Madison Physics Lecture Demonstrations, 257
“utensil music” activity, 63–71
debriefing for, 66–67
extensions for, 67–69
internet connections for, 69–70
materials for, 64
procedure for, 65–66
science concepts in, 64

V
Virginia Tech Physics Lecture Demo, 82
Virtual Circuit Simulator/Lab, 240
Virtual Voltage Circuit Simulator, 107
Visible Thinking, 188
Vision Science, 60

visual participatory analogies. See analogies
von Humboldt, Alexander, 122
von Liebig, Justus, 277

W
wait time, 242–243
Wake Forest University Physics Department, 70, 177, 188, 208, 257, 328
Ward’s Natural Science Co., 82
“Waste Paint Hardener” activity, 126
Watersorb, 127
websites. See Internet connections
weight experiments, 41, 43
Whelmers, 33, 70, 148, 160, 177, 208, 329

Wikipedia
on analogies, 13
on attention, 291
on batteries and bulbs, 107
on buoyancy, 317, 329
on catalysis, 340
on cognitive biases, 299
on cognitive connections, 188
on cognitive load theory, 44, 177
on cognitive neuroscience, 169
on constructivism, 264
on convection, 160
on eddy currents, 248
on electrical generators, 196
on inertia, 257
on LaPlace’s law, 94
on membranes, 218
on memory, 138
on Möbius strips, 22
on optical illusions, 60
on polarization, 272
on rattlebacks, 298
on sound, 70, 148
on sound recording, 115
on static electricity, 208
on superabsorbent polymers, 127
on vortex, 306

Wilson, Edward O., 4
Wilson, Erasmus, 165
Wolfram MathWorld, 22
Woodrow Wilson Leadership Program in Chemistry, 340
wow-and-wonder-before-words approach, 174

Y
Yeats, William Butler, 28

Z
zone of proximal development (ZPD), 172