Ambitious and encouraging, this text for prospective and practicing elementary and middle school science teachers, grounded in contemporary science education reform, is a valuable resource that supplies concrete approaches to support the science and science-integrated engineering learning of each and every student. At its core, it is based on the view that science is its own culture, consisting of unique thought processes, specialized communication traditions, and distinctive methods and tools. Using culture as a starting point and connecting it to effective instructional approaches, the authors describe how a teacher can make science accessible to students who are typically pushed to the fringe—especially students of color and English language learners. Written in a conversational style, the authors capture the tone they use when they teach their own students. The readers are recognized as professional partners in the shared efforts to increase access, reduce inequities, and give all students the opportunities to participate in science.

Changes in the Third Edition:

- Features an entirely new chapter on engineering and its integration with science in K-8 settings.
- Provides fresh attention to the *Framework* and Next Generation Science Standards while distancing previous attention to process skills and inquiry teaching.
- Incorporates the latest research about science practices, classroom discussions, and culturally responsive strategies.
- Retains an accessible writing style that encourages teachers to engage in the challenges of providing equitable and excellent science experiences to all children.
- Updated companion website: online resources provide links to web materials, slideshows specific to each chapter for course instructors' use, and supplemental handouts for in-class activities: www.routledge.com/cw/Settlage.

John Settlage is a Professor at the University of Connecticut. He coordinates the local STEM Teacher Preparation and is a Co-Editor of the *Science Education* journal.

Sherry A. Southerland is a Professor at Florida State University. She is a Co-Editor of the *Science Education* journal and is a mentor to doctoral students and fellow faculty.

Lara K. Smetana is an Associate Professor at Loyola University Chicago and teaches elementary science methods.

Pamela S. Lottero-Perdue is a Professor at Towson University where she teaches science and engineering methods and directs an elementary integrated STEM graduate program.

EDUCATION

Routledge
Taylor & Francis Group
www.routledge.com/education

an informa business

ISBN 978-1-138-11896-6

9 781138 118966

Routledge titles are available as eBook editions in a range of digital formats

Cover image: "Cutler2010107-2" Dave Cutler Copyright © 2017

COMPANION WEBSITE

Please visit the Companion Website at:
www.routledge.com/cw/Settlage

THIRD EDITION

Teaching Science to Every Child

John Settlage, Sherry A. Southerland,
Lara K. Smetana, and Pamela S. Lottero-Perdue

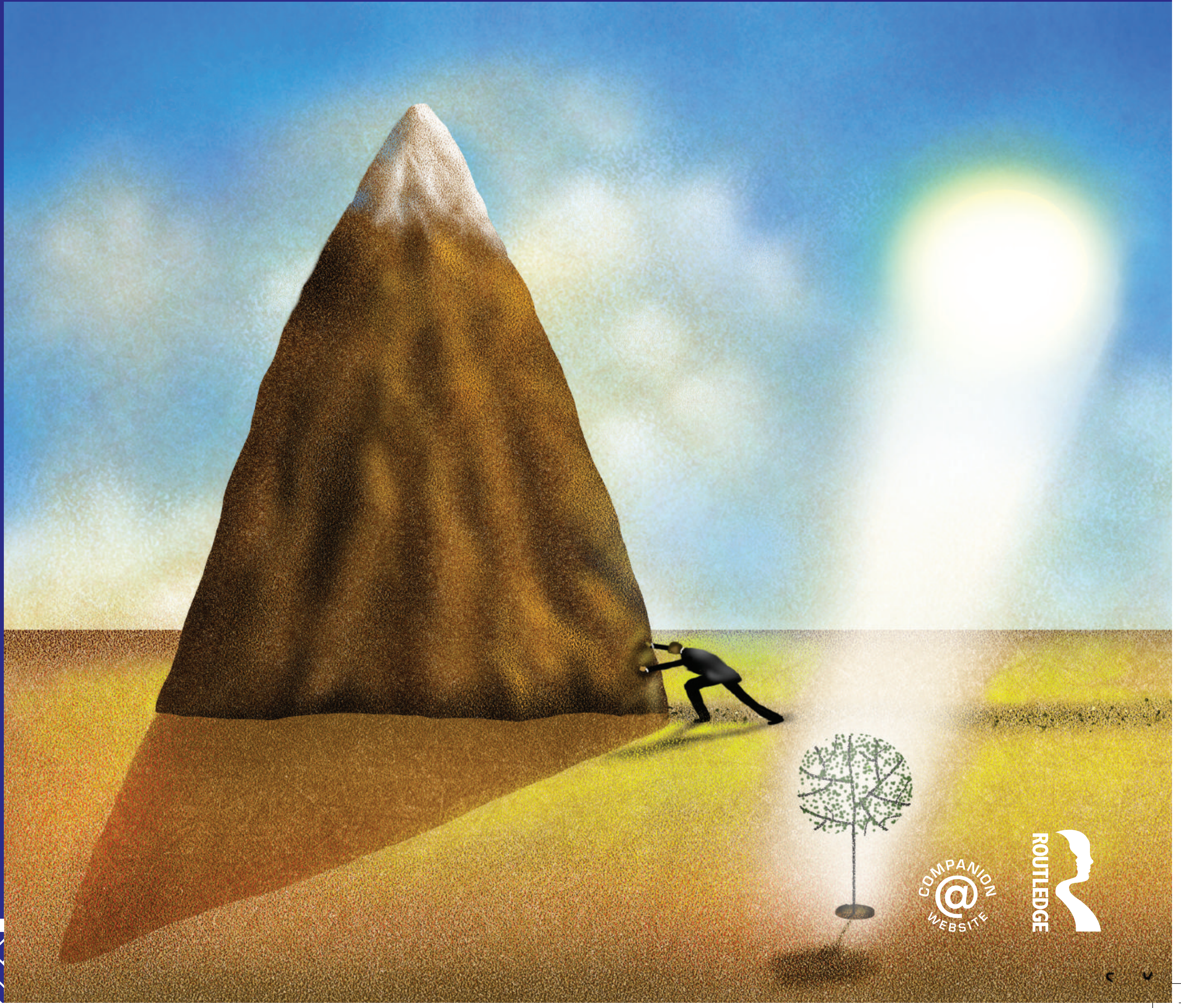
Routledge

THIRD EDITION

Teaching Science to Every Child

USING CULTURE AS A STARTING POINT

John Settlage, Sherry A. Southerland,
Lara K. Smetana, and Pamela S. Lottero-Perdue



Teaching Science to Every Child

Ambitious and encouraging, this text for prospective and practicing elementary and middle school science teachers, grounded in contemporary science education reform, is a valuable resource that supplies concrete approaches to support the science and science-integrated engineering learning of each and every student. At its core, it is based on the view that science is its own culture, consisting of unique thought processes, specialized communication traditions, and distinctive methods and tools. Using culture as a starting point and connecting it to effective instructional approaches, the authors describe how a teacher can make science accessible to students who are typically pushed to the fringe—especially students of color and English language learners. Written in a conversational style, the authors capture the tone they use when they teach their own students. The readers are recognized as professional partners in the shared efforts to increase access, reduce inequities, and give all students the opportunities to participate in science.

Changes in the Third Edition

- Features an entirely new chapter on engineering and its integration with science in K-8 settings.
- Provides fresh attention to the *Framework* and Next Generation Science Standards while distancing previous attention to process skills and inquiry teaching.
- Incorporates the latest research about science practices, classroom discussions, and culturally responsive strategies.
- Retains an accessible writing style that encourages teachers to engage in the challenges of providing equitable and excellent science experiences to all children.
- Updated companion website: online resources provide links to web materials, slideshows specific to each chapter for course instructors' use, and supplemental handouts for in-class activities: www.routledge.com/cw/Settlage.

John Settlage is a Professor at the University of Connecticut. He coordinates the local STEM Teacher Preparation and is a Co-Editor of the *Science Education* journal.

Sherry A. Southerland is a Professor at Florida State University. She is a Co-Editor of the *Science Education* journal and is a mentor to doctoral students and fellow faculty.

Lara K. Smetana is an Associate Professor at Loyola University Chicago and teaches elementary science methods.

Pamela S. Lottero-Perdue is a Professor at Towson University where she teaches science and engineering methods and directs an elementary integrated STEM graduate program.

Teaching Science to Every Child

Using Culture as a Starting Point

Third Edition

John Settlage, Sherry A. Southerland,
Lara K. Smetana, and Pamela S. Lottero-Perdue

Routledge
Taylor & Francis Group
NEW YORK AND LONDON

Third edition published 2018
by Routledge
711 Third Avenue, New York, NY 10017

and by Routledge
2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

Routledge is an imprint of the Taylor & Francis Group, an informa business

First edition published by Routledge 2007

Second edition published by Routledge 2012

Library of Congress Cataloging-in-Publication Data
Names: Settlage, John, author. | Southerland, Sherry A., 1962– author. |
Smetana, Lara K., author. | Lottero-Perdue, Pamela S., author.
Title: Teaching science to every child: using culture as a starting point / John Settlage,
Sherry A. Southerland, Lara K. Smetana, Pamela S. Lottero-Perdue.
Description: Third Edition. | New York: Routledge, 2018. |
Includes bibliographical references and index.
Identifiers: LCCN 2017005857 | ISBN 9781138118959 (hardback) |
ISBN 9781138118966 (paperback) | ISBN 9781315652511 (ebook)
Subjects: LCSH: Science—Study and teaching (Elementary) |
Science—Study and teaching (Middle school) | Multicultural education.
Classification: LCC LB1575 .S48 2018 | DDC 372.35/044—dc23
LC record available at https://lccn.loc.gov/2017005857

ISBN: 978-1-138-11895-9 (hbk)
ISBN: 978-1-138-11896-6 (pbk)
ISBN: 978-1-315-65251-1 (ebk)

Typeset in Minion Pro
by codeMantra

Visit the companion website: www.routledge.com/cw/Settlage

Contents

Foreword xi
Gloria Ladson-Billings

Preface xix

CHAPTER 1 — Providing All Students with Access to Science 1
Chapter Highlights 1
Replacing Stereotypes Regarding Science 2
The Worldview of Science 2
Science as the Work of "Figuring Things Out" 5
The Goal of Proficient Science Students 9
Diversity in Many Forms 11
Causes of Science Achievement Gaps 13
A Clearer Sense for Culture 15
A Broader View of Culture 20
Science as a Culture for Students 21
A Deep and Systemic Look 22
Chapter Summary 22
Key Terms 23
Suggested Readings 24
References 24

CHAPTER 2 — Nature of Science: Seeing Science from a Bird's Eye View 27
Chapter Highlights 27
What Is the Nature of Science? 28
Unpacking Students' Ideas about the Nature of Science...29
Characterizing the Actions of Science: Spheres of Activity and the Mangle of Practice 30
Spheres of Activity and Three-Dimensional Learning 32
Searching for a Functional Understanding of Scientific Practice 32
The Empirical Nature of Science 33
The Creativity of Science and Scientific Knowledge..34
Creativity and the Construction of Explanations...37
Science as a Social Enterprise...40
Scientific Knowledge is Open to Revision...41
Nature of Science and Diverse Classrooms: Science as a Way of Knowing..............45
The Nature of Science and Science Teaching..48
Chapter Summary..49
Key Terms..49
Suggested Readings...50
References..50

CHAPTER 3 — Science Activity: Collecting Information while Investigating 53
Chapter Highlights 53
Teaching the Activities of Science 54
School Science in Transition 55
Observing...56
Observing and Asking Questions 59
Scientific Investigating by Professionals and Children..61
A Cultural Feature of Science: Classifying 62
Measuring within Investigating 64
Investigating: A Foundational Science Activity..65
Testing Our Understandings against the World..66
Benefits of Making Mistakes..68
Predicting and the Scientific Worldview...68
A Predicting Investigation...69
Chapter Summary..70
Key Terms..71
Suggested Readings...71
References..71

CHAPTER 4 — Developing Explanations as a Science Activity...75
Chapter Highlights 75
Conceptual Models..76
Science as an Academic Language 78
Scientific Sense-Making through Experimentation...79

Chapter Summary....96
Key Terms....97
Suggested Readings....98
Resources....98
References....98

CHAPTER 5 — Using Theory to Explain and Understand Science Learning 101
Chapter Highlights....101
What Counts as Learning?....102
Learning as the Personal Construction of Knowledge....112
Learning as the Social Construction of Knowledge....117
Learning Theory for Lifelong Learners....120
Chapter Summary....121
Key Terms....122
Suggested Readings....123
References....123

CHAPTER 6 — Multiple Strategies to Assess Science Learning....127
Chapter Highlights....127
Assessment in Broad Strokes....128
Assessing with Purpose....128
Types of Assessments....130
Formal Assessment....130
Informal Assessment....137
Aligning Assessments with the Curriculum....139
Interview as an Assessment Method....140
Chapter Summary....146
Key Terms....146
Suggested Readings....147
Web and Out-of-School Resources....147
References....148

CHAPTER 7 — Questioning Strategies within Science Teaching....151
Chapter Highlights....151
Behaviorism and Questioning....152
How to Ask Questions....156
Pulling Together the Pieces in a Diverse Classroom....166
Chapter Summary....170
Key Terms....170
Suggested Readings....171
References....171

CHAPTER 8 — Varied Approaches to Science Instruction 173
Chapter Highlights 173
Benefits from Science Learning 174
Teaching Science with the Discovery Approach 175
The Inquiry Approach to Science Teaching 179
Teaching Approaches as Attempts to Solve a Problem 181
Conceptual Change Approach to Science Teaching 183
Varying Science Approaches in Diverse Classrooms 187
Science as an Academic Language 190
Special Needs Populations and Science Teaching Approaches 191
Building an Instructional Sequence 192
The Learning Cycle: Combining Inductive with Deductive Teaching 197
Learning Cycle Teaching as Appropriate for All Students 201
Chapter Summary 202
Key Terms 203
Suggested Readings 204
References 204

CHAPTER 9 — Engineering Design into Science Classrooms 207
Pamela S. Lottero-Perdue
Chapter Highlights 207
Unpacking Ideas about Technology and Engineering 208
Engineering's Distinct Practices 212
Engineering Habits of Mind 219
History and Culture of Engineering 222
Differentiating Science from Engineering 228
Supporting the Inclusion of Engineering in Science Education 233
Access to and Equity within Engineering 235
Implementing Engineering in Science Education 239
Curricular Resources, Approaches, and Tools for Engineering in Science Education 246
Assessing Engineering 256
Chapter Summary 260
Key Terms 261
Suggested Readings 262
Notes 263
References 263

CHAPTER 10 — Managing Classrooms for Science Learning 269
Chapter Highlights 269
Meeting Individual Needs 270
An Environment of Physical Safety 271
Teacher Knowledge Is the Key 276
Starting with Safety 277
Classroom Climate 278
Assessing the Classroom Environment 280

Cooperative Learning....282
English Language Learners and Managing a Productive Classroom....285
Birds of Similar Feathers....287
Chapter Summary....287
Key Terms....288
Suggested Reading....288
References....288

CHAPTER 11 — Teachers Negotiating Different Communities.... 291
Chapter Highlights....291
More than Just Methods....292
A Cautionary Note about Reaction to Difficulties....294
Negotiating Shifting Terrain....295
The Goal of Equitable Science Education....296
Common Barriers to Equitable Science Instruction....297
The Problem with Emphasizing Techniques....297
Equity Cannot Ignore or Deny Differences....299
Teachers Negotiating Various Communities....301
Negotiating the Community of Science....303
Negotiating Your Students' Communities....303
From Ideas to Actions....304
Helping Negotiate between Communities....306
The Classroom as a Community for Negotiation....307
Negotiating Your Own Communities....309
Realistic yet Ambitious Outlooks....313
Chapter Summary....313
Key Terms....314
Suggested Readings....314
References....315

INDEX....317

Foreword

Gloria Ladson-Billings[1]
University of Wisconsin-Madison

I Used to Love Science … and Then I Went to School: The Challenge of School Science in Urban Schools

As a child growing up in West Philadelphia in the 1950s and 1960s, I have fond memories of my family, my community, and school. I was considered a "good" student. I read well, I did my homework, and I was well behaved. However, in my early years, I don't remember my elementary school as a place where I experienced much science teaching. Elementary school was a place that focused on the three Rs, and parents and community members seemed to support that focus. No, my science education took place at home. One of my early science memories comes right after my older brother received a chemistry set for Christmas. As we set about trying to perform the experiments in the accompanying handbook, we learned quickly that scientists (or at least chemists) sometimes had to improvise. We also learned that there were unintended consequences of scientific experimentation.

For example, when we decided to make soap as directed in the chemistry set experiment book, we thought it would be OK to use the previously used cooking grease that my mother kept in a can on the stove top. We didn't know that such impure fat would create a slimy, food-flecked glob that no one in my family would or could use. Another example was when we decided to make the rock candy-slash-sugar crystals. Of course, as applied scientists we were less interested in crystal formation than producing candy. We set out on that experiment during a time when both my parents were gone and my grandfather was left in charge. Again, it did not occur to us that using available resources—in this case, all of the sugar my mother had in the canister—would cause a problem. Our rock candy seemed to form just fine; it was our explanation to my mother upon her return that did not seem to go over well.

Sometime around fifth grade, science became really important in our school. This was the same time that the Russians launched a successful satellite. Suddenly, we began receiving science books, and the *Weekly Reader* began to have a very deliberate science message. However, the school's version of science wasn't like the kind of science my brother and I were doing from his chemistry set. There was no mystery, no uncertainty, no unintended consequences and, most importantly, no fun. Science—when we had it—was boring. It consisted of reading chapters, memorizing facts, and answering the questions at the end of each chapter. I found it boring, and I was a good reader. I cannot imagine how horrible it was for the struggling readers.

By the time I got to junior high school where I learned that science was a special subject. I knew it was special because we had it in special classrooms. These rooms had big black covered table tops with sinks on one end and what I would soon learn was a gas outlet for something called a "Bunsen Burner." My seventh grade teacher, Mr. McLean, had a preciseness about himself. There was a specific way that the science notebook had to be kept, he said, because scientists work in very precise ways. Already I was starting to get nervous. Mr. McLean insisted that we head our papers in a particular way. He also insisted that we use specific vocabulary—hypothesis, observations, conclusions—and that we include precise diagrams and illustrations with our lab work. I liked doing the labs—they reminded me of my chemistry set antics—but I was so nervous about the preciseness of the reporting that I often paid little attention to what I was supposed to be learning. For example, I could recite every single part of the microscope, but I don't think I knew what any of those parts really did.

One of the assignments for seventh grade science was a leaf collection assignment. We were to locate at least ten different kinds of deciduous leaves, mount and label them, and create a booklet. I think the one thing I understood about the assignment was the word *booklet*. The thing that Mr. McLean did not understand about me was that I traveled by trolley and bus to attend that school because my mother thought it would give me a shot at a better education. Most of my classmates lived close to the school, and living close to the school meant that they lived close to Bartram's Garden, the oldest botanical garden in the country. I lived in a neighborhood where the city had removed most of the trees and replanted one species—Sycamores. I did not have access to the same variety my mostly White classmates did.

My mother, in her attempt to help, talked with a coworker who had a part-time job in a greenhouse. On the eve of the day, my leaf booklet was due my mother came home proudly displaying a set of leaves. They were absolutely beautiful. Unfortunately, they were not deciduous and neither my mother nor I really knew the difference. I placed my leaves on paper, labeled each one, covered each page with plastic wrap, and made a nice construction paper cover. I failed the project because while my classmates turned in maples, oaks, elms, and many other leaves from trees native to the Philadelphia environs, I turned in a booklet with orange tree, lemon tree, rubber tree, and other leaves from a greenhouse. I felt stupid and vowed to try to do science "by the book."

In eighth grade, I had a wonderful teacher named Ms. Mowbray. I was excited by the idea that we had a woman as a science teacher. Ms. Mowbray made science fun. We did lots of experiments and got to ask lots of questions. I did well in her class. However, on one of the last extra-credit assignments I ran into a problem. We were supposed to construct a "Cartesian Diver." Once again I was coming home with an assignment that was beyond my parents' understanding. This time I did understand what Ms. Mowbray wanted. She wanted us to understand "buoyancy" and that an object is buoyant in water due to the amount of water it displaces. She wanted us to know that if the weight of the water that is displaced by an object in water exceeds the weight of the object then the object will float. I understood that. It helped me understand why people float in large bodies of water. My problem with the project was that it required a glass jar (we did not have plastic bottles), an eyedropper, and a semipermeable membrane. The only component of the project I could get was the semipermeable membrane, which was a balloon. I could not get the glass jar because glass bottles had a 2 cents deposit attached to them. I could not get the eyedropper because every eyedropper in my house was in use with someone's medicine.

By high school, I had an after-school job and was in a better position to marshal school supplies on my own. I was a good student and earned good grades in science courses, especially chemistry. For a brief moment, I considered a career in the sciences, but I have always been puzzled by the way science is seen as the special purview of some students while others are systematically excluded from participation.

Science and African-American Students

As an African-American student growing up in a working-class household and community, I should be a science education statistic. However, a number of factors converged to ensure that my K-12 schooling experience left me with enough social and cultural capital to enter college and pursue advanced studies. But it is important that we look at what is happening to African-American students in science today. In the 2003 Quality Counts report published by *Education Week*, we learned that although many states are doing their best to recruit and retain skilled teachers, few efforts are targeted at finding teachers for the students who need them most. Teacher quality is important because the existing research indicates that effective teachers can get an additional year's worth of learning out of students and the effect of having a string of ineffective teachers is cumulative.

Although we have read about the achievement gap, the digital gap, and the learning gap, we have not addressed the "teacher gap." This gap indicates that students of color in high poverty schools are more likely to have teachers who do not have college majors or minors in the subjects they teach. They are more likely to have teachers who are not certified in the subjects they teach. They are more likely to be inexperienced teachers without the benefit of student teaching before they face a classroom of students.

According to the MetLife 2001 American Teacher Study,

> students overall, and black students in particular, have high expectations for their future. However, teachers and principals in heavily minority schools have lower expectations for their students. Teachers in schools with high proportions of students of color report lower quality teaching and teachers in schools with high proportions of students of color are less satisfied with several school relationships (e.g. with principals, colleagues, students) and less committed to the profession.
>
> (p. 10)

The achievement gap we reference emerges in a context that includes a teacher gap (as well as a resource gap). As we look at the National Assessment of Educational Progress (NAEP) data (National Center for Education Statistics, 2000), we know that the largest achievement gaps are in eighth grade science on which 40 percent of White students score at or above proficient compared with only 6 percent of African-American and 11 percent of Latino students. At each assessed grade level (4, 8, and 12), Black and Latino students score significantly lower than their White counterparts.

Any number of assumptions are tied to African-American students' lack of science proficiency. Some of the "usual suspects" are that the students lack the motivation, fail to have supportive parents, and/or do not have prerequisite skills for science learning. Haycock (2001) indicates that when the Education Trust staff queries adults about the racial/ethnic achievement gap, the comments tend to be:

> "They're too poor." "Their parents don't care." "They come to school without an adequate breakfast." "They don't have enough books in the home." "Indeed, there aren't enough parents in the home." Their reasons, in other words, are always about the children and their families. Young people, however, have different answers. They talk about teachers who often do not know the subjects they are teaching. They talk about counselors who consistently underestimate their potential and place them in lower-level courses. They talk about principals who dismiss their concerns. And they talk about a curriculum and a set of expectations that feel so miserably low-level that they literally bore the students right out the school door. When we ask, "What about the things that the adults are always talking about—neighborhood violence, single-parent homes, and so on?"—the young people's responses are fascinating. "Sure, those matter," they say. "But what hurts us more is that you teach us less."
>
> (p. 3)

In this discussion, I want to focus on the idea that the students lack the motivation or aptitude for science. I want to argue that African-American students continue to be interested in science but often attend schools where they have little or no opportunity to learn "real" science. To "test" student interest in science, I have been interviewing preschool and kindergarten aged African-American students to determine how their interests converge with science. I have purposely not interviewed older students because the nature of their school science experiences may unduly influence what they believe about science. I have been interviewing four- to five-year-old children at an African-American church and five- to six-year-olds who are attending kindergarten. I used Brodhagen's (1995) and Beane's (2002) framing questions of "What do you want to know about yourself?" and "What do you want to know about the world?" The following are a sample of the questions the children posed (I edited out those that were not science questions):

- Why is my shadow long sometimes and short sometimes?
- Why do people have different color skin?
- Why do the leaves fall off the tree in the winter and come back in the summer?
- How can a big airplane stay up in the air?
- Why does stuff come in your eyes when you are sleeping?
- How does the weatherman know what the weather is going to be the day before?
- Why does the moon look different? Sometimes it's a big moon and sometimes it's a little teeny moon?
- How can the moon and sun be out at the same time?
- Why do some of my mother's flowers come back every year and some she has to plant every year?
- Why is it late at my house and early at my grandma's? (I think this is a time zone question.)
- How does the baby get out of the mommy's stomach?
- Why does your mother say, "no jumping" when she bakes a cake?
- How does the thermometer know you're sick?

These questions clearly illustrate that African-American students do have an interest in the scientific world. Their questions cut across a variety of science areas—biology, astronomy, chemistry, and physics. Yet, we are led to believe that inner city, urban students of color have little or no interest in science.

How Science Could Be

If the students continue to come to school with interests in science, how can we maintain and invigorate their interests? From my research with teachers who are effective teachers of African-American students, I argue that science could be different. Science could incorporate what I have termed "Culturally Relevant Pedagogy." This pedagogy incorporates academic achievement, cultural competence, and sociopolitical consciousness.

Academic achievement is in some way a misnomer for what I mean theoretically. I am not referring merely to student performance on standard measures. Rather I am focusing on student learning as a much broader construct. Thus, when it comes to science education I am referring to what it is important to know. Is it necessary to study dinosaurs at every elementary grade level or are there some science concepts and knowledge that students should learn or at least experience at different grade levels?

In the classrooms I studied, teachers demanded that students study and learn to high levels. One teacher taught the students from the graduate curriculum she was studying to obtain her Master's degree. In her classroom there were posters of the brain and its various parts. Students use neurological terms and query their teacher each Thursday morning as to what she studied the day before. In Barb Brodhagen's classroom, her students discussed the earlier questions—"what do I want to learn about myself and what do I want to learn about the world?" The students settle on a small set of questions that become the basis for the curriculum. One semester the students decided the question they wanted answered was "Will I live to be 100?" That question provoked study in family and genealogical histories, actuarial charts, environmental effects on life span, and an investigation of genetics and genetic diseases. What both of these classrooms had in common were knowledgeable and skillful teachers who were unafraid of deviating from prescribed curriculum and challenging students beyond conventional course materials.

The second aspect of culturally relevant pedagogy is cultural competence. This refers to the degree to which student culture is logically and meaningfully incorporated into the curriculum. The typical science attempts at this involve a list of famous African-American scientists and inventors. The students rarely see the relevance or connection of these scientists—particularly when they only show up in February—and find their presentation no more meaningful than anything else in the curriculum. Instead, culturally relevant teachers take the time to "study" the students, their habits, and their behaviors.

In one classroom of African-American students a teacher asked, "How many people don't like to drink milk?" About a third of the students raised their hands. "What is it about milk that you don't like?" Even the way she phrased the question—not "why don't you like milk?"—invited the students to participate. Her question indicated that there was something about milk that might be problematic. Some students talked about not liking the taste of the milk. Others talked about not minding the taste but getting sick soon after drinking it. As the students shared their problems with milk some of the others who were milk drinkers shared stories of siblings and other family members who had trouble drinking milk. The teacher then asked the students what would they think if they learned that in a classroom of White children almost all of the students drank milk. "Wow," exclaimed one boy, "you mean white milk is for White people?" That comment brought a nervous laugh among the students, but the teacher said, "Well, I don't know that white milk is for White people, but it is true that it is difficult for some people of African descent to digest."

This conversation moved the students into a school-wide survey of milk drinkers. It also gave the teacher an opportunity to teach the students about genetic characteristics, lactose intolerance, and food allergies. The science that most students want to engage in is science that helps them answer their questions. While middle class students may acquiesce and tolerate the science the school curriculum offers them, many of the students who are struggling to engage with school need a curriculum that engages them.

Cultural competence is important because it helps students understand the strengths and limitations of their culture. In Lee's 1999 study of standards-based science teaching, she learned that although the teachers taught exactly what the curriculum asked of them, students' worldviews are shaped by powerful forces outside of the classroom. In the aftermath of Hurricane Andrew, teachers tried to determine how much of the science learning helped students to understand the weather disaster. Unfortunately, Black and Latino students reported that the hurricane was the result of the wickedness and evil that pervaded the South Florida region. The hurricane was God's way of punishing them. The teachers did not know what to do with this worldview, and students left the school experience with the notion that school and home are strictly separate worlds. The fact that the students experience more success in the world of their home galvanizes their feelings of alienation toward the school.

The third component of culturally relevant pedagogy is sociopolitical consciousness. In my mind, this is the "so-what" aspect of schooling. How many times have we heard students ask the question, "Why do we have to learn this?" only to be told, "because some day you're going to need this." We all know how much we ALL need the periodic chart of elements in our daily lives. Sociopolitical consciousness helps students understand the way citizens in a democratic society need scientific knowledge to make informed decisions. Maria Torres-Guzman studied a group of high school students in an alternative school. The students' major project at the school was investigating a dumpsite in their neighborhood. The students learned that the site contained toxic materials and ultimately raised questions about the way poor communities of color are vulnerable to environmental racism. The students' passion for this project was fueled by the fact that they understood that what they were doing had a payoff for the here and now, not the "someday" that teachers often promise.

There is a science out there in which African-American students desperately want to participate. This is a science that explains the epidemic of diabetes or AIDS in their community. This is a science that challenges social constructions like race. This is a science that people can mobilize to fight social injustice AND intellectually empower people. This is a science that allows students to do something rather than sit passively while something is done to them.

My focus has been on African-American students, but I have begun to see how improving schooling for them is likely to improve schooling for all students. If we begin to strengthen science teaching for those who are most vulnerable in our system, we are likely to strengthen it for everyone. We are no longer in a society that can afford to have people be scientifically illiterate. We are no longer in a society that can afford to weed out students or push them through arbitrary sieves called biology, chemistry, and physics. We are no longer in a society that can afford to send some students to a course called general science that actually would better be called "reading about science." We need every student to leave our schools excited about and engaged in science so that they can have more career and vocational choices open to them and can actively participate in the decision making that democracy requires. We need to turn school into a place where our students can continue to like science. (And in case anybody knows Ms. Mowbray, please tell her that I've made my Cartesian diver.)

Note

1 Dr. Gloria Ladson-Billings was named in 2016 as one of the most influential educational scholars in the nation. She has a strong reputation as a researcher, advocate, and leader in education. However, as you will discover in her story, her beginnings in science education as a child were not especially positive. Although her childhood struggles and successes occurred 50 years ago, there remains the potential for today's students to undergo similar difficulties. When teachers fail to recognize the resources students draw upon during science activities, this creates possibilities for miseducation. We urge you to consider what YOU should do differently to avoid reproducing the unpleasant school science experiences that the young Gloria had to endure.

References

Beane, J. A. (2002). Beyond self-interest: A democratic core curriculum. *Educational Leadership, 59*(7), 25–28.

Brodhagen, B. (1995). The situation made us special. In M. Apple & J. Bean (Eds.), *Democratic schools* (pp. 83–100). Alexandria, VA: Association for Supervision and Curriculum Development.

Haycock, K. (2001). Helping all students achieve: Closing the achievement gap. *Educational Leadership, 58*(6), 1–9.

Lee, O. (1999). Science knowledge, world views, and information sources in social and cultural contexts: Making sense after a natural disaster. *American Educational Research Journal, 36*, 187–219.

MetLife. (2001). *The American teacher: Key elements of quality schools*. New York: Author.

National Center for Education Statistics. (2000). The nation's report card [Document No. NCES 2002–452]. Washington, DC: U.S. Department of Education.

Torres-Guzman, M. E. (1992). Stories of hope in the midst of despair: Culturally responsive education for Latino students in an alternative high school in New York City. In M. Saravia-Shore & S. F. Avizu (Eds.), *Language and culture in learning: Teaching Spanish to native speakers of Spanish*. New York: Garland.

Preface

Learning to teach science greatly benefits from real-life attempts to do so. The stumbles teachers make as they deliver a science lesson offer unparalleled professional learning opportunities. Becoming better can almost always happen by thinking back on a partially successful attempt. You learn which goofs to never repeat. And for the parts that went well, you retain those for future use. Over time, error frequency goes down, and the smoothness and coherence of science lessons improve. The continuous improvement is possible when mistakes can be identified and alternative techniques are implemented. The challenge for someone new to science teaching is that lessons sometimes go badly and it's not completely obvious why. If the teacher has sufficient insight to identify the problem, knowing what to do instead may not be obvious. During those science teaching moments where you could most benefit from good advice, especially when you are a fulltime classroom teacher, it is uncommon for another adult to be available to witness your challenges, identify your problems, and offer helpful solutions. Learning from experience doesn't work as well in isolation. Just as students learn from the skillful guidance of the teacher, so too will a novice teacher benefit from timely and wise mentoring. How can you learn to become a better teacher of elementary and middle school students if you: (a) are expected to learn while on the job and (b) nobody is present to coach you about your efforts?

Teaching science in ways that support every students' learning is an incredibly complex undertaking. As such, it can't be fixed by looking up the problem and downloading the solution. Classrooms are rich in human drama. Fixing a challenge isn't something that can be accomplished with a phrase or a flourish. There aren't any magic spells or easy answers. The best teachers we've known over the years embrace the interpersonal relationships in classrooms and use those as resources to support efforts for everyone to learn science. Building those relationships requires taking risks to establish and maintain trust. Better teachers communicate they care by holding students to high expectations—the students feel challenged because they sense the teacher believes in them. Interpersonal trust and positive expectations are communicated by teachers' actions as much as by what is said. What teachers do and what they say arise from their commitments and ambitions. Our hope for this book is that it will provide you with a compelling philosophy about teaching science to every child. We supply techniques that illustrate this philosophy, but we anticipate you will acquire more strategies as you advance through your career. This book does not pretend to serve as a how-to book. You won't even find a lesson plan in this text. What you will find instead are consistent messages to guide you to teach science in ways responsive to every student who enters your classroom.

Science Education as a K-12 Fundamental

As educators, we do not feel it is appropriate to act as if only certain individuals are capable of learning science. At a very fundamental level, we believe science holds incredible power for those who can apply scientific reasoning to everyday circumstances. This describes the goal of scientific literacy. Rather than simply knowing how to read science, people who understand how science works can take greater control over their lives. At a more political level, we believe that a democratic society will be stronger when its citizens rely on scientific knowledge and thought processes. Debates about the environment, energy, and other scientific topics ought to be informed by wisdom and not simply emotion.

However, most science teaching methods' resources mention student diversity in only one section. Otherwise, science is presented as if it is free of cultural influences. From a practical perspective, future teachers deserve to be shown techniques that deliberately and consistently take into account student diversity. This means adjusting science instruction to be responsive to students with varying physical and cognitive abilities. This requires providing different forms of assistance for English learners. This demands recognizing that students may come from backgrounds typically excluded from scientific careers. At the core, rather than offer general statements about the value of teaching science to all students, as authors of a teaching textbook and as instructors in science methods courses, we show how to do this across many facets of science teaching. In a very real sense, we wrote the book we wished has been available to us as we began our careers as science teachers.

Taking Your Place at the Front of a Classroom

Somewhere during your education program, you will have the sudden realization that you are going to be a teacher. As students enter their education program that outcome is somewhat nebulous. At some point each of us has a "glimpse" of exactly what it means to be a teacher—the responsibilities it entails, the expertise required to do it well, the amount of work that seems to always lie ahead. Just as with many important life goals, your progress toward becoming a teacher probably has been a mix of your imagination and a considerable amount of hard work. But there is often a moment when each of us realizes that what we have been working toward is about to happen. Before too long, you won't be a student sitting in class being taught by someone else: you are going to be that someone else. The person you have wanted to become—an adult who inspires students, who is enthusiastic about learning, who believes that education opens incredible opportunities, a person who serves as a role model for the citizens of tomorrow—believe it or not, that's where you're headed. This realization is likely to fill you with excitement and insecurity.

We know this feeling because we've had it ourselves. Even though our names are on the cover of this textbook, most people we know perceive us as science teachers. Our job titles say we are education professors, but we are not strangers to classrooms. We are constantly working with teachers and working with kids, to help all of us learn science and become better at teaching it. Over the years, it has become easier for us to step to the front of a classroom full of students. But it still makes us nervous. Often, we don't sleep well the night before we meet a new class. And every now and then during a science lesson, we marvel at the fact that we are actually in charge of a group of students who are learning science. Our intent with this book is for you to embrace the benefits of helping students become excited about what they are learning and the fact that they are becoming good at it.

Approaching Science as a Culture

We used to think culture was something outsiders possess, something that existed somewhere else. For example, the news media reports cultural factors associated with tensions around the globe. Universities describe their study abroad courses as a "cultural immersion" experience. Even the cultural centers on campus emphasize traditions that are generally viewed as outside of mainstream America. What many of us fail to recognize is that each of us is the product of a culture, even though the authors themselves resisted this possibility when they were undergraduates. Over time, as we became associated with people raised under different circumstances, we came to appreciate cultural differences. These are differences that distinguish others' cultures from the cultures that influenced us even though we may not fully have recognized the influences upon who we have become.

We believe that treating science as a culture is one way to make the subject more accessible to a wide range of people. Science is more than strange equipment and odd terminology. Instead, science is embodied in how the members of the culture think, communicate, and behave. For those comfortable participating in science, they may not even be fully aware of the cultural norms because they feel so "natural" to them. On the other hand, we suspect that students (and adults) who find science to be "unnatural" might feel that way because no one ever told them about the cultural norms of science. From a teaching perspective, science learning involves students in acquiring vocabulary and remembering procedures. But it should also emphasize the ways of thinking and behaving that allow people to be recognized as scientific. In other words, if science feels foreign and mysterious, then the solution is to explain to the cultural norms and offer practice participating within the culture.

The idea of science as a culture is not an original idea. We think this book is special because we have translated a philosophical view of science into the practicalities of classroom science teaching. To teach science that uses culture as a starting point carries the implicit message that science is not only a subject that should be made available to each and every student. In addition, the cultural view of science contains the belief that it is the responsibility of teachers and schools to provide a high quality science education to all students. This is a departure from the "junior scientist" ideal with the unexamined belief that some children are scientists-in-training and others are not. At the very least, the authors of this book are battling against the typical exclusion of certain students from science. However, the idea of inclusion as represented by the slogan “science for all” is not sufficiently specific. Evidence of this can be found in standardized test data that continually show the inequities in science achievement based upon gender, ethnicity, and so on. Using culture as a starting point, this book is designed to inform and inspire teachers to teach science in ways that are more welcoming and more effective to a wider spectrum of students.

Overview of This Book

Our expectation is that the material and ideas presented in this text will be complemented by the local expertise of your science methods course instructor. That individual was selected by your college or university because of their expertise in local classrooms. As authors of this textbook, we view your instructor as our collaborator. We share the responsibility of setting you on a path of science teaching excellence. In this way, we anticipate that what you will read and what you hear will reinforce each other. That might also mean that the messages you receive may not be 100 per cent aligned. This is because professional perspectives vary. Every state in the USA is undergoing transformation, and it is sufficiently challenging for the authors to stay abreast of what is occurring within our respective towns and cities. We have necessarily aimed to describe general tendencies whereas your methods instructors can offer valued additional insights specific to local teachers and schools. In that regard, we have had to choose from among all the possible science teaching topics to emphasize those that are unique and important.

This book begins with an emphasis on giving students access to science. The disparities within scientific fields by gender, race, ethnicity, and abilities are something that we believe can be changed. Chapter 1 provides foundational information about realizing this goal. In turn, Chapter 2 presents a view of science that offers a more humanistic perspective. Next, we describe how the scientific activities of scientists can be mirrored in elementary and middle school classrooms. We rely on “science activity” to do this. In Chapter 3 appear guidelines for supporting students with scientific investigation. Chapter 4 takes science activity further by showing how to support students in developing scientific explanations. Those chapters provide a view of science education defined by contemporary reforms and portray science in ways that improve accessibility to you and your students.

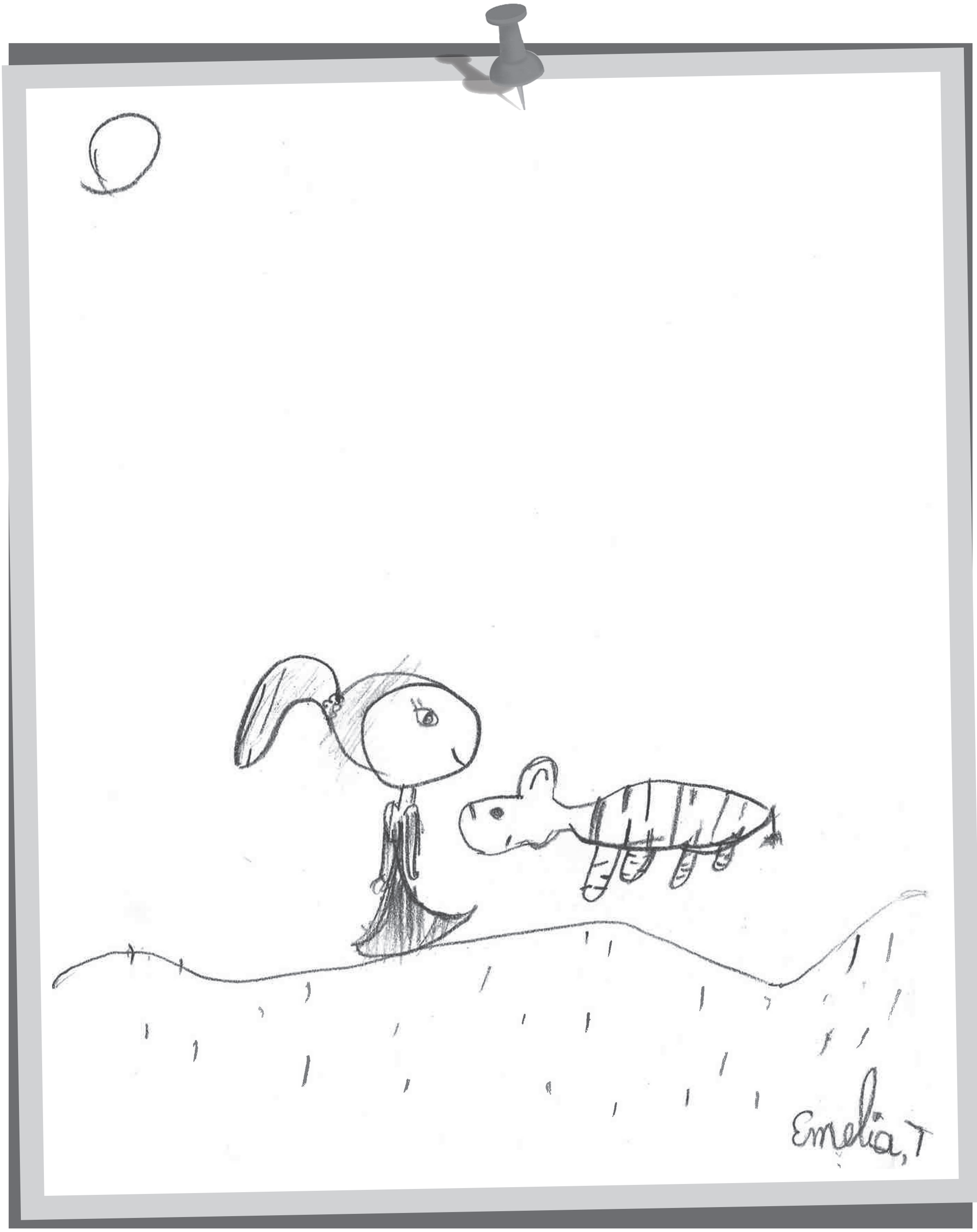
Science learning by children is the focus of Chapter 5 where you will encounter multiple theories to assist with planning and diagnosing your science teaching. Chapter 6 offers many strategies to assess students’ science learning in ways that will inform efforts to improve your teaching effectiveness. Chapter 7 provides strategies for posing questions to students for ways in which you can steer their responses in productive directions. Chapter 8 summarizes the development over the years of different approaches to science instruction.

An entirely new chapter appears in this edition that responds to discussions about STEM education. Most teacher preparation programs have courses to address Science and Technology and Math; Engineering is often neglected. Chapter 9 provides an in-depth and strategic effort to remedy this problem. Chapter 10 addresses the logistical and managerial challenges associated with experiential approaches to science teaching. And we round out our discussions of student diversity and science instruction with Chapter 11. There you will encounter a teacher who struggles and succeeds to realize the goals put forth by this text.

From the previous edition, the process skills and inquiry teaching that were emphasized have been replaced. The fresh information within the *Framework* and the associated *Next Generation*

Science Standards deserved attention. Also, the former Point/Counterpoint feature has been removed, in large part because the field of education is changing far too rapidly to be captured within miniaturized debates. In contrast, we have preserved portions of the text from the feedback we received from instructors and students. We have retained our signature writing style. We wanted to be honest and sincere in capturing how we teach our own students. What you see in print accurately reflects the tone and style of our classroom teaching. We hope you find value in what we share and in how we chose to say it.

New to this edition is artwork by children who were given these prompts: draw yourself engaging in science and engineering. The children who provided these drawings were participating in a summer camp at The Chicago Academy of Sciences / Peggy Notebaert Nature Museum. The Nature Museum Summer Camp offers children ages four to eleven exciting and enriching nature-based learning experiences to explore local urban habitats. Campers spent their day outside building, climbing, digging, and inventing with natural and recycled materials. The intent was to enhance their imaginations and problem-solving skills while cultivating a love for nature and learning. Campers were encouraged to take the lead during activities in the provided spaces as they explored the nature of Chicago with tools chosen (or built!) by them. Campers used the indoor and outdoor grounds of the Museum as their classroom to foster critical thinking, social-emotional skills and science practices through hands-on experiences with museum collections, exhibits and live animals. The resulting kid art appears as opening illustrations to each chapter.


Emelia,T

one
Providing All Students with Access to Science

Chapter Highlights

- The science classroom is ideal for replacing stereotypes regarding science and scientists with representations that promote student engagement and participation.
- Science relies on a particular worldview based in on special habits of mind (e.g., curiosity, openness, and skepticism). These views carry certain values that create distinctions between science and other worldviews.
- Students can become engaged in the culture of science when science classrooms are organized around "figuring things out" and creating explanations for phenomena. This approach is framed by attending to (a) disciplinary core ideas, (b) crosscutting concepts, and (c) scientific practices.
- Scientific proficiency offers intellectual tools for students to gain control over their lives, attain a wider range of career opportunities, and participate in a more informed citizenry. The efforts to provide "science for all" include females, students from all cultures, English language learners, and students with a variety of physical and cognitive abilities.
- Gaps in measures of students' science knowledge reveal different performances by students from various demographic groups. Rather than calling this difference an "achievement gap," it is more instructive to consider this an "opportunity gap."
- Cultures are evident within families, social organizations, and workplaces and are signified by the cultural objects and actions. Accepting one's own cultural legacy is an important phase of appreciating the value of other cultures. This includes recognizing that one can have membership in multiple cultures.

- Representing science as a culture is an approach that can increase students' access to and regard for a field that often feels foreign and uninviting.
- The teacher's role in the classroom can be as a cultural ambassador who continually frames science as a sense-making activity, and through the pursuit of sense-making, guides all students in participating in the culture of science.

Replacing Stereotypes Regarding Science

Science has a culture all its own with certain norms, materials, and actions. However, just as any culture can be reduced to stereotypes, science can be represented in ways that are not fully accurate. The caricature of a scientist takes the form of a White man with wild, uncontrollable hair who is wearing a lab coat and works in a disorganized and dangerous lab. Among famous scientists, we could include Albert Einstein (and he did have the wild hair), Thomas Edison (his lab was full of strange equipment), and the cartoon scientists on television and in movies. The problem with stereotypes is that they portray the actions and behaviors of an entire group in narrow and often inaccurate ways. The same holds for the scientist stereotype.

We are not equating racial and ethnic stereotypes with stereotypes of scientists—that would trivialize racism and bigotry. However, there are substantial differences between how science is portrayed in the media and the actual culture of science. What's the harm in that? The common scientist stereotype may cause students to feel science is not for them. In other words, the stereotype of the White male scientist does not serve as an effective role model to draw a wide range of students into the culture of science. In fact, such stereotypes may repel many students from science.

One of our responsibilities as teachers is to displace stereotypes, including those that persist for science and scientists. To accomplish this, we can immerse our students in activities, conversations, and other experiences that authentically represent scientific culture. The strategy we'd like you to consider is this: if we can help children understand what it means to be a scientist, which includes developing their competence with the cultural norms of science, then more students will believe they can think like scientists and use these ways of thinking to understand their lives. That, in short, is the goal of science teaching.

The Worldview of Science

Science has a particular worldview. A worldview describes the perspective through which one interprets the world. The scientific worldview offers a perspective that is not necessarily the most effective in all situations. And yet, the power of a scientific worldview offers a unique method for understanding the world. Consequently, as one approaches the role of science teacher, one ought to give the science perspective strong consideration (Bell, Lewenstein, Shouse, & Feder, 2009). Many dimensions of daily life benefit from our use of other worldviews: religious, aesthetic, moral, and so on. Consider the contrasting ways in which a painter and a meteorologist might look up toward the sky. The artist could look at the sky and consider how it could be represented with paint: the shades of white, the edges of the clouds, and the gradations of color from straight overhead down to the horizon. In contrast, the scientist taking in the same scene would make sense of it differently: the shape of the clouds suggests the temperature of the air, the direction of their movement indicates the presence of low and high pressure, and the changing color of the clouds gives an idea about the approach of a cold or warm front.

Neither way of looking at the sky is superior. The traditions of the artist's viewpoint and the outlook of the scientist serve different purposes. Instead of arguing which way of looking at and thinking about the sky is better, we should acknowledge that artists and scientists hold different worldviews. The criteria for the appropriateness of their perspectives rest entirely upon the communities in which they work. The artist's view is shaped by the ways of artists. The scientist's view is similarly influenced by the community of science.

One foundational and distinctive facet of the scientific worldview is the insistence on patterns in the world we can understand. Scientists feel that through careful questioning and observing, humans can identify patterns and that this knowledge can be used to make accurate predictions. You might ask, "What's the point of identifying patterns? What's the use of being able to make good predictions?" Scientists are driven to understand the world, to explain natural phenomena. Although there are times when scientists want to understand something to solve a problem, at its essence, the scientific drive to understand and explain the universe is the ultimate prize. The satisfaction of making good predictions comes from solving a mystery and resolving something that was unknown. With this comes a sense of control and power resulting from having achieved a greater sense for how the universe operates.

Scientists share certain basic beliefs and attitudes about appropriate ways of going about scientific work. These dispositions hint at the culture with which scientists approach the world. Scientists presume the universe operates in ways that are comprehensible. Scientists believe that by using the intellect, with the aid of instruments that extend the senses, scientific activity can identify patterns in nature. Scientists also operate with the expectation that they can trace the causes of natural events. Within the scientific culture, there are many features shared with other worldviews. We like to think of these as habits of mind (Dewey, 1910) that can be developed through appropriate rehearsals and practice.

Habits of Mind

Each culture has certain value systems. Individuals within a culture are judged and shaped by those values. The values endorsed by a given culture influence actions of those recognized as members of that culture. For example, some of us believe working hard is its own reward and that doing a good job should not be based on whether there is some reward that will come to us when we finish the task. People who adhere to this value system look down on those who believe that a person ought to be paid according to how well they did a job. These two value systems are products of contrasting cultures. Another example of a value system is being a vegetarian. This set of beliefs leads to certain behaviors: treating certain foods as acceptable and viewing other foods as objectionable. Sometimes this can create conflicts because people's value systems are in opposition to each other. The point is that what one believes often controls how he or she will act. Simultaneously, a person's actions often reflect his or her beliefs.

Because the value system of science influences the way in which individuals think, these ways of thinking are shared traditions that represent the **scientific habits of mind**. These habits are not automatically embedded in the minds of certain people. There aren't people who are "born" to be scientific. Instead, these values are learned. They are transmitted from one generation of scientists to the next. People new to science and in the process of becoming members of the culture have to learn the scientific habits of mind along with the behaviors consistent with that value system. Otherwise, an individual won't be recognized as a legitimate participant in science.

Curiosity

The drive to understand something arises from the need to satisfy curiosity. Why do some objects sink whereas others float? Why do plants in one location seem healthy and green whereas similar plants in another place are weak and yellow? Why is the phase of the moon associated with unusual human behaviors? Questions such as these are the driving force for curious people. Being curious is one of the most important scientific habits of mind. Fortunately, most students begin their education with a great deal of curiosity. Every child is curious about objects that move, especially unusual animals (have you ever been at a zoo when a day care group is on a field trip?). The curiosity is there, and it seems appropriate to state that children are predisposed to think like scientists because of their curiosity.

However, it is possible to extinguish a child's curiosity—and the process of schooling sometimes does just that. If a child is led to believe that there are only right or wrong answers, then this can make curiosity seem unimportant. If the activities of science class are more about filling out a worksheet than figuring out an answer to an interesting question, then curiosity may get in the way. A child's curiosity can be shoved to the side if learning is reduced to avoiding mistakes and receiving recognition and praise. Almost inevitably, and this is one of the many wonders of teaching science, with the right materials and a supportive atmosphere, a child's curiosity can be resurrected.

Openness to New Ideas

Another scientific habit of mind is a willingness to consider new ideas. In contrast to the stereotype of the lone scientist working in isolation, science is very much a social endeavor. Although an individual scientist might figure out a problem on his or her own, the idea has to be considered, discussed, and debated by the scientific community before it is accepted or rejected. As members of the scientific culture, individuals are expected to remain open to the prospect that new and better explanations are possible.

As a culture, science allows for the possibility that the current and accepted explanations may not be sufficient. Somebody might gather new data revealing flaws in a current scientific theory or bring a fresh perspective to existing information. There is a long history of solid scientific ideas being replaced by new and better explanations. The culture of science accepts the likelihood that better explanations will emerge as time goes on. That cultural norm translates into individual scientists needing to be open to new ideas and needing to consider the opinions of others.

This can be a source of internal tension. After all, scientists are driven by a curiosity to find and explain natural phenomena. We can imagine the excitement and relief that a scientist must experience when he or she uncovers a pattern that has been hard to identify. Understandably, a scientist would feel a sense of accomplishment and ownership of his or her explanation. Indeed, there is a tradition in science where the first person to make a discovery (of a new species, of a new star, or of a new theory) has his or her name attached to it. But to then suggest that this person must also be open to new ideas? We can sympathize with scientists' difficulty with this concept. In a later chapter, we will examine a similar tension students experience as they struggle to resolve their personal explanations with those of the scientific community.

Skepticism

The habit of mind of **skepticism** is a value that is especially distinct within science. Examples of skepticism in action are when someone asks: "Are you sure? Can you provide some facts to convince me? What evidence supports that claim?" In certain respects, being open to new ideas and exhibiting skepticism work hand in hand. Even though cynicism is commonly equated with skepticism, the scientific worldview does not treat skepticism as a negative trait. A cynic is suspicious of people and institutions, suspecting there is always a selfish motivation behind the things others do. In contrast, a skeptic is doubtful about the claims people make and always looks for more evidence to support these claims. A skeptic always needs data to become convinced, whereas there is no amount of data that satisfies a genuine cynic.

The need for data and evidence is central to the skepticism habit of mind. The more evidence someone uses to support his or her ideas, the more likely other scientists will accept these ideas. Arguments in other fields such as politics or the arts or philosophy are not as dependent upon data. Individuals involved in those fields rely on persuasiveness, emotion, and beliefs, but in science, high-quality data that address the question being explored are like gold.

Skepticism could be the reason science is often in conflict with other cultures. Skepticism and faith are exact opposites. Skeptics will demand the reasons that support what we know, whereas people with faith do not expect justification for what they know. Because faith and skepticism rely upon conflicting criteria for claims of truth, the worldviews are in opposition to each other. The way to resolve this dilemma is to consider the idea of cultural membership: each of us is a member of multiple cultures. Just as you change your role when you go from your home to work, to school, and to worship, individuals can shift their worldviews depending on the situation. While various culture may contradict, that doesn't force those into being completely incompatible.

Emotions as Habits of Mind

A last habit of mind characteristic of science is made up of the emotional components. While our stereotype of scientists may share more with Spock from Star Trek (i.e., thinking divorced from emotions), it is important to note that a scientist's quest for understanding and explaining comes with and is driven by an assortment of emotions—interest, puzzlement, bafflement, curiosity, even joy—what Keller calls the "joy of going at it" (1983, p. 125). Far from being detrimental or incidental to the work of scientists, emotions are intimately tied with the doing of science (Jaber & Hammer, 2016). The frustration of a failed experiment as well as the thrills from discoveries are exceedingly familiar to professional scientists. The space for genuine emotions ranging from excitement to disappointment should be acknowledged as consistent with scientific activity—in the world of professional scientists as well as during your classroom's science activities.

For Reflection and Discussion

How do scientific habits of mind correspond to the way science is typically represented in schools? What sorts of activities might we expect an instructor to use if he or she decided to emphasize the habits of mind throughout the science curriculum? What sorts of comments might a teacher offer to students in an effort to nurture the scientific habits of mind?

Science as the Work of "Figuring Things Out"

> Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements—knowledge and practice—are essential.
>
> (National Research Council, 2012, p. 26)

Scientists do their work by constructing and refining explanations of the natural world. Accordingly, the *Framework for K-12 Science Education* (National Research Council [NRC], 2012), which served as the foundation for the *Next Generation Science Standards* (NGSS; NGSS Lead States, 2013), emphasizes the necessity of students experiencing knowledge construction. The processes consist of three integrated dimensions: core ideas, scientific practices, and crosscutting concepts. Together, these are known as three-dimensional science (Krajcik, Codere, Dahsah, Bayer, & Mun, 2014):

Disciplinary Core Ideas. The core ideas are the material commonly thought of as classroom science. Rather than attempting to be comprehensive, disciplinary core ideas are most essential to students as they become more scientifically knowledgeable.

Crosscutting Concepts. Certain scientific concepts cut across all the disciplines (i.e., biology, physics, chemistry, etc.). These concepts unify scientific thinking and support students as they develop productive explanations about the natural world. Students will encounter these crosscutting concepts throughout their K-12 science education and will develop increasing depth of understanding and appreciation.

Scientific Practices. More than just process skills, scientific practices describe the combined physical and mental activities that students apply as they build explanations of the natural world. The key scientific practices are:

1. Asking scientific questions and defining engineering problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing scientific explanations and designing engineering solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Science learners build useful science content knowledge while participating in scientific practices. Conversely, students develop greater capacity with science practices as those are employed while pursuing scientific understandings. Teaching the three dimensions should not occur in isolation. Rather, science instruction should coordinate across the dimensions with the expectation that these will mutually support students' science learning. These three dimensions reflect how science is practiced in the real world and are to be used by students as they work to make sense of phenomena.

How is three-dimensional science learning to be achieved in the classroom? We may need to fundamentally rethink the purpose of hands-on science activities. Instead of treating investigations as "kinesthetic" experiences or simply a way to mix things up by not doing book work, classroom science experiences provide a rich intellectual context for developing scientific explanations. Clearly, this is much more complex than having children keep track of cloud types or observing animal behavior. Teachers are being asked to make these shifts because the three dimensions accurately mirror the work of scientists. In short, rather than design lessons where kids pretend to be scientists, the three-dimensional approach engages students in authentic science rather than a make-believe version.

Philosophically, by approaching science teaching and learning using a three-dimensional mindset allows students to participate in the culture of science. Too often, students are left to their imaginations about what adult scientists do. Typical elementary or middle school students are rarely able to shadow scientists while those professionals collect evidence or collaborate with others to make sense of data. While that type of exposure might be ideal, placing students in the scientists' workplace is not feasible. Just as physical education teachers give students the chance to personally engage in sporting activities, and music teachers provide students the opportunities to participate in musical production, so too should teachers of science provide instruction where students are not pretending but are instead participating in science.

Science instruction compatible with three-dimensional learning will not seem attainable if teachers view science as occurring during a specific lesson. Previous generations of teachers might have believed they had covered a concept because students did one activity. The provided curriculum may reinforce this compartmentalized view of science. But as science teaching becomes a more refined profession, there is widespread agreement that a checklist mentality has not been sufficient. Consequently, the scope of science concepts has been reduced even as teachers are expected to spend more time addressing these essential ideas. Children require multiple opportunities to master the disciplinary core ideas. Three-dimensional learning supports such

Patterns. Observing regularities in the natural world, develop mechanisms for classifying this information, and considering the factors that could have produced the patterns.

Cause and Effect. Pattern identification leads to questions about what prompted those outcomes to occur. This requires more than identifying the sequence of events. Instead there is the need to identify whether one factor caused the next event to happen. This becomes the basis for experimentation.

Scale, Proportion, and Quantity. The mathematics of bigness and smallness is crucial for understanding natural phenomena. Quantifying changes in amounts and appreciating probabilities are concepts important across studies of the living and nonliving world.

Systems and System Models. Thinking about systems requires the identification of all components within a defined system and excluding everything external to that sysem. Systems involve components as well as the complex ways those interact with one another. Creating physical and conceptual models helps test and explain the system.

Energy and Matter. Energy causes changes within systems and matter moves around within systems. Being able to trace those cycles and appreciate the conservation of the stuff are scientific concepts applicable across the disciplines

Structure and Function. How an object or organism is put together influences how it responds and performs. Sensitivity to these interactions is as important to study anatomy and physiology as it is to building devices to solve engineering challenges.

Stability and Change. The universe tends to push everything towards randomness. Living systems resist these forces through stabilizing processes. Engineered systems are designed to respond to change. Preservation in the response to outside pressures allows life to continue and for structures to remain.

FIGURE 1.1. Crosscutting Concepts (National Center for Education Statistics, 2015).

curricular goals. A one-day science activity to cover an idea such as the water cycle instead requires a series of activities, conversations, and projects that build robust understandings for students. The rush to move onto the next topic is falling into disfavor and being replaced by three-dimensional science learning in which scientific practices and crosscutting concepts are developed.

The overarching instructional goal of science teaching is to generate opportunities for students to apply scientific practices, create explanations of phenomena that address core ideas, and connect these actions and information to crosscutting concepts. That is, science classrooms should be framed as places for students to "figure things out" as they solve intriguing problems or questions. Science lessons become less about what a teacher delivers to students. Instead, science lessons represent teachers' efforts to guide students toward generating productive explanations of phenomena. Learning vocabulary and completing worksheets will continue but as supports of three-dimensional science learning.

> In order to be fully engaged in the practices, it's simply not enough to merely learn about the science idea, however creative and hands-on the task may be. To engage in the practices, really participate in them, a student has to frame the task as an exploration. **The intellectual work of the classroom has to be centered on figuring out how or why something happens**.
>
> (Passmore, 2014)

Throughout the United States, there is a discernible transition from activity-based science activities toward three-dimensional science learning. To illustrate this transition, let's compare the two approaches centered on the same science content. In the first approach, students place beans on damp paper towels that are sealed into plastic bags. Days later, the students are asked to dissect the beans. They are challenged to identify the various structures found in the sprouting seed by referring to various informational resources such as textbooks or online sites. In addition, they are expected to describe the functions those structures serve. As we might expect, the students are excited to see the changes in the beans over time. On dissection day, they carefully pulled apart the beans and sketched the structures. The students were engaged, and studying the objects promoted great interest.

The second approach relies on essentially the same materials: bean seeds and dampened paper towels sealed into plastic bags. However, the teacher in this class begins the study of seed germination with an investigation: comparing the growth of bean seeds in a closet versus equivalent bean seeds placed on the windowsill. When students discover that, contrary to their expectations, the bean seeds germinated equally well in both conditions, the teacher challenges them to address this question: "How can a seed grow in the dark?" Students discuss the possibilities and decide on a plan. They assemble many seed-in-bag set-ups so they can dissect beans at different stages of germination. After about a week, they will compare the findings for closeted versus windowsill seeds. Each day, a new team of students pulls apart beans, draw structures, and presents its findings to the class. As a whole group, they compare the results across the days. An idea emerges the first leaf that emerges for a seed is vital. They learn that this structure is called the cotyledon, and they speculate that this seed part provides energy to the plant to support its growth during germination. The evidence for this idea? This class documented that this structure shrinks over time. Throughout their work activity, the students were engaged, excited, and in more than a couple of instances, arguing about the results and interpretations on the way to lunch.

This "figuring out" taking place in the second classroom was not a free for all. Rather, the teacher was strategic in setting up such a productive learning opportunity. To the untrained eye, this might be perceived as mere messing about—as if playing with natural materials would lead to the spontaneous understandings of scientific concepts (Hawkins, 1965). The teacher decided in advance on the targeted ideas, crosscutting concepts, and scientific practices that would likely arise as the class sought to explain the seed germination process. The crosscutting concept was *Structure & Function* (see Figure 1.1), a key scientific practice was "engaging in argument from evidence," and the disciplinary core idea was "plants depend on water and light to grow." By comparison, the first approach to this activity felt less aligned to the scientific culture. In addition, the students worked on things that did not feel quite so rigorous and meaningful. The contrasts between the two approaches are subtle yet substantial. Central to the teacher's planning and actions was providing classroom conditions that encouraged student interactions allowing them to generate meaning from firsthand experiences. Science learning, as advocated within the *Framework* and subsequent *NGSS*, obliges teachers to guide students as they engage in productive, meaning-making work in the classroom—work that involves talk, joint attention, and shared activity aimed at the construction and critique of explanations (Ford, 2008).

The Goal of Proficient Science Students

Think back upon the science you experienced as a young learner. What do you remember? Some adults recall keeping a journal of the moon's phases or rolling toys down ramps. Others recollect long lists of words they had to define. These memorable activities don't provide adequate signposts for guiding science teaching in this era. Gone is the acceptability of teachers doing science activities that have little relationship to authentic science. Students in such settings might be interested or engaged. But this approach ignores contemporary policy and the emerging consensus about effective classroom science. As guides for teacher planning, student "enjoyment" is no longer a sufficient goal. Instead, teachers and schools are being asked to aim for something different. Simply having fun is not the endpoint of classroom science anymore.

The National Research Council has proposed that the new goal of science education is individual student proficiency. The *Framework for K-12 Science Education* (National Research Council, 2012) calls for all students to become proficient in science by the time they graduate from high school. Framing science educational goals as proficiency indicates that students need to learn how to generate and evaluate scientific explanations, understand how scientific knowledge is developed, appreciate what makes science different from other ways of knowing, and how to participate in the practices of science (Duschl, Schweingruber, & Shouse, 2007). Science proficiency includes the learning of vital science concepts. Added to this fundamental storehouse of knowledge is learning how *to do science*—to participate in sense-making about the natural world (National Research Council, 2012). Students' science learning is intimately tied to the investigating phenomena and constructing explanations tied to the observations and data. For this to be realized will require a "fundamental change in the way science is taught" (NAS, 2015, p. 1), and that begins with re-envisioning science instruction by teachers. These shifts are a substantial departure from previous science reform efforts but perhaps not in ways most people fully realize. This newness is not about setting aside books in favor of activities; that has been something science educators have been advocating for nearly 100 years (Champagne & Klopfer, 1980; Craig, 1928). Another mistaken belief is that what is newly beneficial to science education is integrating technology into instruction. The fancy digital devices, some claim as transformative, are being described in the very same way as innovations that are now extinct (Standage, 2014). What elevates the current move to reform science education is its scope. Rather than focusing on creating new instructional materials and training teachers to appropriately implement those, the science reform movement is more systematic than ever before. That is, the units of change are organizations. To realize the goal of universal science proficiency requires coordination across systems. Teachers are essential, but there is increasing recognition that we should not leave them to thrive or perish by continuing to isolate them in their individual classrooms. Just as students need support, guidance, and feedback, so too are classroom teachers going to require continual and collaborative participation in the work at hand.

Who Should Become Science Proficient?

> By the end of the 12th grade, students should have gained sufficient knowledge of the practices, crosscutting concepts, and core ideas of science and engineering to engage in public discussions on science-related issues, to be critical consumers of scientific information related to their everyday lives, and to continue to learn about science throughout their lives. … It is especially important to note that **the above goals are for all students, not just those who pursue careers in science, engineering, or technology** or those who continue on to higher education.
>
> (National Research Council, 2012, p. 9)

Why do we teach literature? Why do we teach mathematics? Is it because we expect all students to become best-selling authors or accountants? Probably not. Language arts and mathematics are commonly understood to be the essential components of a broader education. They represent a body of knowledge schools are to help students master so they have a better chance to lead productive and fulfilling lives. We propose that science is no different. The goal of science teaching has moved away from the desire of the 20th-century United States to assemble the next generation of scientists. Instead, science teaching now focuses on supporting every student to develop abilities to scientifically approach problems. Whether a student ultimately ends up in science field is left for that individual to decide. And neither the adults nor the student in elementary or middle school has enough insight to make such determinations until after a child has had years of high quality exposure to science. When does a student make that decision to be a science person or not? Maybe not until college. In the meantime, educators and educational systems should be designed to ensure that when that decision is being made it follows a considerable amount of time of participating in authentic science.

To teach science in ways that encourage certain students to become scientists and discourage others is an unacceptable scheme. Instead, our educational system should consider all students as deserving our attention to move them toward scientific proficiency. Withholding opportunities to participate in science because of a mistaken belief about who will become a doctor or engineer or physicist borders on negligence. Rather than treating science classes as a filter for separating the potential scientists from the nonscientists, scientific proficiency is a baseline feature of being educated. In addition to expecting high school graduates to be able to read and write, everyone who earns a diploma should enjoy "scientific literacy." As indicated in by the quote that began this section, schools should provide *every* student with their deserved opportunities to learn science.

Scientists and science educators acknowledge that scientific knowledge and skills are necessary for an everyday life in the 21st century. In a sense, science helps empower citizens.

Individuals who are more scientifically proficient will have greater control over the choices they make about their lives. As a consequence, science instruction should not exclusively, or even primarily, focus on producing the next generation of scientists. Instead, the goals are to engage all students in making sense of the world scientifically. Again, this is a systemic undertaking that requires individual teachers to commit themselves to these goals as well as providing teachers with organizational structures to support those efforts. All of this needs to occur without delay because waiting until upper elementary is far too late. As early as pre-kindergarten, students can begin developing the practices and knowledge to support their growth toward scientific proficiency by the time they reach twelfth grade. Reading skills in kindergarten are substantively different from reading in high school, and not just because the words are bigger and the books are heavier. There is increased sophistication from being incrementally educated about how to interact with texts. The same applies to science. Exposure to scientific phenomena by very young children might look like play. Those concrete experiences are foundational to high school graduate science proficiency. Letter recognition and phonemic awareness for reading have their parallels in science. Those are described in greater detail in the subsequent chapters. At this point, we simply want to elevate the regard for science education as something much more than something for "science types" or that can begin after children have been in school for several years.

Diversity in Many Forms

As we rise above the misbegotten sense that the purpose of teaching science is preparing certain students to become scientists, we redirect our attention to the value of teaching science *for all students*. It is one thing to say "all students" but what were members of the National Research Council thinking. Who exactly is the "all"? The following definition leaves little room for doubt:

> **SCIENCE IS FOR ALL STUDENTS.** This principle is one of equity and excellence. Science in our schools must be for all students: All students, regardless of age, sex, cultural or ethnic background, disabilities, aspirations, or interest and motivation in science.
> (National Research Council, 1996, p. 20)

The ambition is clear: scientific proficiency is not a goal reserved for a subset of students. Students from all backgrounds, all abilities, and all personality types are to receive science instruction that aligns with the three-dimensional ambitions identified by the *Framework*. Why this emphasis on the "all"? Part of the rationale comes from past patterns of science achievement among groups of students, part comes from demographic changes in the American population, and part comes from changing educational policy. In the following sections, we will explore some of the categories of students now being targeted for scientific literacy.

Ethnic Diversity

Most students from non-European American cultures do not score as well in science as their more Western, mainstream counterparts. Figure 1.2 shows science NAEP scores for two grade levels and across ethnic categories (fourth grade science was not tested in 2011). The graphs show the average scores on the science test.

What can we surmise from these data? Clearly, there have been gains as average scores within each ethnic group have increased over the years. As a whole, fourth and eighth graders are showing elevated science scores. On the other hand, the differences between students designated as

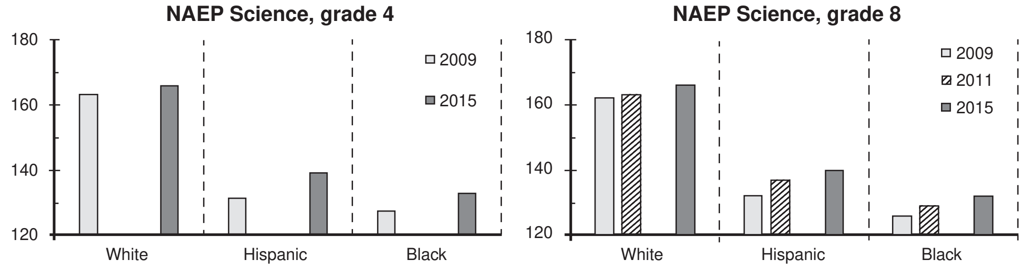


FIGURE 1.2. Science performance on the National Assessment for Education Progress with results presented by ethnicity (National Center for Education Statistics, 2015).

White and their Black and Hispanic peers remain large. These disparities are commonly referred to as **achievement gaps**. The achievement gaps for fourth graders went from 36 to 30 (comparing Whites to Blacks) and from 32 to 27 (comparing Whites to Hispanics). This pattern is quite similar for eighth graders who took the NAEP Science test. These might be viewed as improvements because the science performance disparities based on ethnicity are shrinking. The issue is that at the current pace, you may be retiring from teaching by the time those gaps are gone. Thirty years of ethnic disparity is a very long time—and that assumes we continue to make progress.

Socioeconomic Diversity

Related to the patterns of science achievement by ethnic groups, students of lower socioeconomic status tend to struggle in school more than their more affluent peers do. This relationship between socioeconomic status and student science proficiency is particularly troubling as 21 percent of school-aged children in the United States are currently living in poverty—a 23.5 percent increase in two decades—and the highest rate of children living in poverty of any of the Western democratic nations (National Center for Educational Statistics, 2016). Students are commonly categorized as poor if their family income is low enough to qualify for financial assistance for food. Students who do not qualify for this program are not necessarily wealthy. This means there is a considerable range of family wealth concealed within the category "does not qualify for free/reduce priced lunch," which is why we must be cautious with these comparisons. Regardless, the achievement gaps for students categorized as FRPL versus not-FRPL reveal another type of science disparity (Figure 1.3).

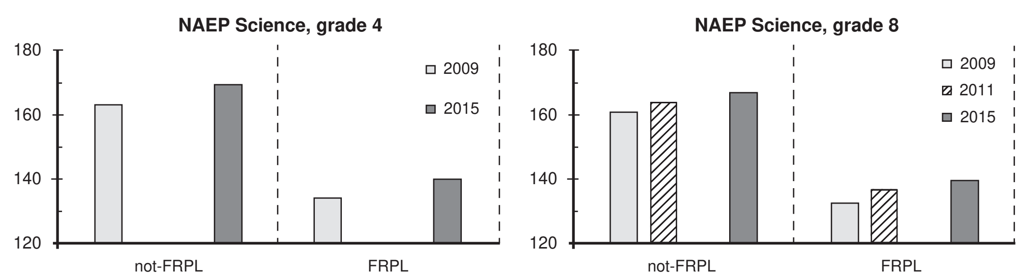


FIGURE 1.3. Student science performance on the National Assessment of Educational Progress with results disaggregated by income level. FRPL refers to Free and Reduced Price Lunch and is based on family income falling below a poverty level (National Center for Education Statistics, 2015).

Ability Diversity and Physical Disability

Approximately 12 percent of the student population of the United States had a disabling condition (Lynch, 2000). These conditions include learning disabilities (45 percent of the total number of disabled students), speech and language impairments (20 percent), mental retardation (10 percent), serious emotional impairments (roughly 10 percent), orthopedic impairments (1 percent), hearing impairments (1 percent), and other impairments, including attention deficit disorder (1 percent). With the passage of the Individuals with Disabilities Education Act, many more students with disabilities are being integrated into mainstream classrooms. Science education reform includes those who have cognitive disabilities or who are in some way physically challenged as part of the population deserving quality science experiences.

Those who might claim that students with difficulty processing ideas ought not to engage in science are probably taking a too-narrow view of the subject. A deliberate and thorough observation of materials and events is an essential feature of doing science. Manipulating objects to appreciate causes and effects is also considered scientific. When we embrace the complexity of science and realize that mastery of knowledge is not all that is involved, we have a new vision of who is capable of learning science.

The challenges that people with physical disabilities face can often be regarded as mainly a matter of access, although teacher expectations weigh heavily as well. As teachers, we should strive to provide every student with access to science, not just for legal reasons but also because of a commitment to the goal of teaching science to all students. Sharon Lynch (2000) brought up a wonderfully insightful point: Albert Einstein, Niels Bohr, and Leonardo da Vinci, all scientific visionaries, had learning disabilities and overcame their disabilities in ways that factored into their eventual success.

Causes of Science Achievement Gaps

It is one thing to claim to teach science to all the children in our classrooms and quite another thing to be successful in doing it. An important step is to consider possible reasons for gaps in scores on nationwide measures for students from different demographic groups. Why is it that girls, students of color, students learning English, and students with disabilities tend to lag behind their White, male counterparts in terms of science performance and participation? Typically, speculations focus on the students. Girls are often described as being less interested in science than boys and, for whatever reason (biology or culture), having lower science aptitude. Simply put, some people continue to suggest that it is harder for girls to think scientifically. In the 21st century, with women doctors, astronauts, and physicists, this is clearly a controversial remark—and so the ability of women in science continues to be a source of public debate (e.g., Newkirk, 2005).

As we consider uneven performance in science, a common and misleading suggestion is that the student and the student's family are the source of difficulty. If students are not successful in science, then using this mindset, it is because their homes, upbringing, or even genetics fail to prepare them for the rigors of school. Attributing failure in this manner uses **deficit perspectives** (Milner, 2012), inaccurate beliefs that children who come to school without prerequisite skills, knowledge, and abilities are destined to always fall beyond their peers. In this fashion, we sometimes hear opinions about the source of disparities residing within the individual students, as if there is deficiency in their character, grit, or persistence. Interventions have been attempted to "fix" individual problems (such as self-regulation) but those projects deserve to be viewed with skepticism (Andrzejewski, Davis, Bruening, & Poirier, 2016). One problem with deficit mentality is that it fails to explain the science success of students from historically underrepresented groups. In settings where teachers and schools do not ascribe to a deficit mentality, students from a wide range of backgrounds can display exceptionally high science achievement.

Unequal Science Opportunities within the Same Setting

Geneva Gay (2000), in her book *Culturally Responsive Teaching*, reminded us that teacher expectations substantially influence the teaching provided to students. Although teachers may *believe* that all students *can* learn, they may not *expect* some students *to* learn. Thus, teachers may challenge and support some students while allowing others to be in classrooms without insisting they be engaged or holding them to high expectations. Good and Brophy (1994) labeled this situation a "self-fulfilling prophecy"—a phrase originating from Merton (1948). If teachers expect students to be either high or low achievers, teachers will act in ways that communicate these expectations. Although often subtle, the expectations are recognized by students with science performance corresponding to those messages. Ultimately, the expectations held by teachers become true. This relationship between teachers' expectations and students' performance has been documented in a wealth of research conducted in a variety of settings (Workman, 2012).

Working from a wealth of research literature, Gay described how White boys tend to be provided with disproportionate learning opportunities within classrooms. Again and again, researchers have documented that male students in science classroom are asked the more difficult questions, given more challenging responsibilities, and provided with stronger acknowledgments of their efforts by teachers. These students are expected to succeed in science because of a twisted belief about biological destiny. The adults' beliefs about who can become a scientist manifest as explicit and subtle messages. They become signals that support one segment of the school population while also discouraging the others. Teachers typically do not hold the same science expectations for girls, students of color, students of poverty, or students with disabilities. A considerable body of research describes how students in these demographic categories are asked fewer and lower-level questions, are provided with less critical feedback, are assigned easier tasks, and are given less acknowledgment of their success (Workman, 2012). Less is expected concerning these students' science capabilities. The wrong-headed prediction that student success is related to gender, socioeconomic class, and ethnicity promotes a climate where preferential treatment dominates. Tragically, these expectations prove to be "true" when student outcomes are viewed through these biased perspectives. Students expected to be successful produce high scores and more learning gains. What often goes unacknowledged is that even though students may be in the same classroom, the differences in their outcomes reflect unequal opportunities because of teachers' actions.

To unreflective educators, a teacher's role in this situation often goes unrecognized while their inequitable regard and treatment of students reinforces their view of who has the "capacity" to learn. Yes, teachers can exert powerful influence on students' science achievement through their expectations of students, but this doesn't always have to be negative. Promisingly, we can also communicate more equitable expectations by monitoring who we select to ask questions, the difficulty of the challenges we present various students, and the nature of the praise and feedback we offer to different students.

You may have seen the graphic showing three children of different heights who try to watch a sporting event but are blocked by a fence. The second picture shows a failed effort to fix each child's limitations. Under the caption "equality" each child is now standing on the same-sized box. However, because of their different heights, only the tallest individual can now watch the game. The next image is labeled “equity” because each child is standing on a different number of boxes, and all three can see the game. The shortest kid stands on three boxes and is now high enough to see over the fence. The medium child needs just two boxes to have a clear view, and the tall kid only has to use one box. This graphic is used to illustrate the difference between equality and equity. Giving every child the same amount of support constitutes an equal distribution. An equivalent would be serving the same-sized lunch to every student from kindergarten through high school: it’s “fair” because nobody gets an unequal share. The problem with this thinking is that it ignores the practical question about what is enough. In contrast, equity pays attention to the amount of support the individual requires. Rather than choosing an arbitrary level of support, an equity-oriented approach would supply each person according to his or her needs. In the fence and box example, not every child was given the same number of boxes. Instead, the resources were distributed to provide equal access.

Missing in this allegory is the construction of the fence. Instead of seeing inequities as deficits in the children, we might need to consider why the fence is there in the first place. Maybe the fence is intended to provide limited access—as if being tall was desirable and being short was not. This is not just a fictional or philosophical discussion about equity and science. Just a few generations ago, there were practices within schools that segregated girls from being able to access science: there were fewer female science teachers, there were societal biases against girls going into science, and the lists of required courses were different for boys and girls. None of this should be interpreted as implying that all students should not be fairly treated. In many situations, the level of support and intervention may need to vary depending on the individual. But society is also capable of imposing barriers that are preferentially harmful and potentially discriminatory to a subset of the larger population.

Lessening Inequitable Access to Science

The content of science may spawn opportunity gaps. Given that even the National Science Foundation (1994) recognizes science as a Western, masculine way of thinking, it seems almost inevitable that some students will find science more accessible than do others. However, just as a teacher ought to hold high expectations for all students, the teacher also has the responsibility for helping students understand scientific ways of thinking. We advocate that this can best be accomplished by reconsidering science as a culture. In other words, science is not merely a fixed body of knowledge that resides on a shelf. Instead, it is a way of knowing shaped by those legitimately participating in science. As teachers, making explicit the culture of science becomes a way of increasing opportunities for students. This cultural orientation toward science teaching is the focus of the next section.

A Clearer Sense for Culture

Throughout our lives, we shift our associations based on our desire to belong to a group. For a child, this happens by being part of a family. This starts with an awareness of parents and siblings and may expand to include the extended family: grandparents, cousins, and so on. What an individual includes within “me” is more than just himself or herself. The self also encompasses his or her position within the family unit. As the child grows, the “we” expands to include friends, neighbors, coworkers, and teammates. As a group member, the individual acquires an understanding of the group’s standards: what to wear, when to speak, how to behave, and so on. Such is the process of becoming a social being. Part of going to school involves learning how to function within a wider variety of groups. Labaree (2010) has even gone so far as to say that this is exactly what American schools do best: bring people together to develop a sense of being within a group. We consider these groups as cultures given our alignment to Sonia Nieto's definition of **culture**:

> Culture can be understood as the ever-changing values, traditions, social and political relationships, and worldviews shared by a group of people bound together by a combination of factors that can include a common history, geographic location, language, social class and/or religion. Thus it includes not only tangibles such as foods, holidays, dress, and artistic expression but also less tangible manifestations such as communication style, attitudes, values, and family relationships.
>
> (Nieto, 1992, p. 111)

When a culture is self-contained and insulated from other cultures, its members may not recognize the unique and distinctive aspects. When people spend much of their life isolated within a culture, they may suppose their cultural traditions are normal. To a certain extent, this is accurate. A norm is defined as a typical aspect of a group. In testing, the most common score within a group is the norm. Standing when you hear the national anthem broadcast is a cultural norm.

Being confined within a particular culture may leave defining traditions unexamined. As a result, people may claim they do not have any culture because the norms are felt to be universal. Their thinking and actions are pretty much standard and if other traditions are encountered those variations seem peculiar, quirky, or weird. Quite naturally, people associate with other people who share their traditions. It would be an unusual person who is constantly an outsider from all traditions. But in an increasingly connected and complex world, students need assistance with recognizing that each of us is a member of a culture and to also accept other cultures as legitimate even though they are different. It can be challenging for many of us to recognize that our upbringing influenced how we think, what we say, and how we act. In short, we're instilled with cultures even if we don't fully appreciate those influences.

Two Components of Culture

Cultures consist of two components: the objects and the actions. The **objects** of a culture are the physical tools and culturally specific ways in which those tools are used. The **actions** of a culture are the ways in which participants in the social group interact with each other. In the culture of a particular ethnic group, the objects would include clothing, language, food, and knowledge base, and the actions would include their traditions, social structures, gender roles, and communication styles.

FIGURE 1.4. Successfully navigating another culture includes an understanding of symbols: This sign from Mexico indicates a no-parking zone.

When we travel to a place where the culture is different from our own, we aren't always sure how to fit in. We may not know the language, wear the appropriate clothes, or understand the road signs (see Figure 1.4). Each of those aspects represents the objects of a culture. Certain actions of another culture can feel foreign to us: we're not sure about the traditions for forming a line, how to appropriately acknowledge an older person, or which of our behaviors might be viewed as insensitive.

Such an awareness of cultural differences occurs when we find ourselves in unusual circumstances. This doesn't mean one must travel to a distant country to experience these sensations. Even without *object* and *actions* labeling to sort through the sensations, you may experience these when attending a celebration in someone's house of worship, shopping in an ethnic store, or eating a meal in a unique restaurant. In those instances, the "insiders" were comfortable with the surroundings and sensations. As the "outsider," your daily and unexamined way of acting and thinking didn't feel quite so natural. The odd and often uncomfortable sensations when you are quite literally "out of place" highlight other cultures as well as your own. There may be glimmers of realization that someone has a culture that differs from the one you've been temporarily experiencing.

Often it isn't until we become immersed in another culture that we become aware of the defining features of our own culture. When a person can seize the novelty, he or she can recognize that culture is not something exotic, foreign, and remote. Instead, there is an elevated appreciation that culture is a part of each of us. Those who claim that they do not have a cultural affiliation or regard their traditions as just normal have not had enough thoughtful exposure to other cultures. When someone from a different culture asks you to explain your holiday traditions and you recognize that your experiences are not necessarily shared by everyone, then you are closer to seeing that you are a member of a culture. It seems necessary to acknowledge a personal cultural identity to become effective in working with students from a wide array of cultural backgrounds.

Rather than discussing cultures that feel alien and remote, we will examine two cultures very close to home. We begin by considering the cultural elements of a classroom and then consider science's cultural features. The purpose is to reinforce culture as more than something "out there." This will move us closer to the goal of seeing that culture shapes who you are and how others perceive you.

Describing a Classroom Using a Cultural Lens

Picture a typical classroom. Maybe you could imagine the classroom where you learned from your favorite teacher. Or it could be a classroom you recently visited. It doesn't have to be an ideal classroom, but it should be an easy one for you to visualize. Consider how you would describe it to a person who had not visited that place. What features of the classroom you would you describe to someone employed by a construction firm? If your classroom description is to be effective, you would need to anticipate the features in which a construction expert would have an interest. Someone from the construction "culture" tends to view his or her world from the vantage point of ceilings and floors, lights and windows, ventilation and acoustics, and other parts of the physical environment. You might describe how the classrooms looks and feels at different times of the day and during various seasons. If your classroom has windows, then the incoming light's qualities might be noteworthy as would the view one has when looking out. Given the construction person's professional interests, he or she would probably be curious more about where and how the books are stored within the classroom than about the types of books available to the students to read.

Imagine a different challenge—describing the classroom to an anthropologist. This anthropologist is going to want to learn about people within the classroom rather than the heating and cooling system. To describe a classroom to the anthropologist, you would emphasize the people's interactions: the manner in which they talk to each other, the ways they organize themselves into groups, the types of objects they use, and the routines in which they participate. This description would include the changes taking place throughout a school day and the types of activities occurring at various points in the school year. The furniture of the classroom would be relevant to the extent that it informs the anthropologist's appreciation for the human and the social aspects of the classroom.

There are all kinds of things special about classrooms that make them very different from other spaces where people work. One obvious difference is the furniture: it's all built in proportion to the children, which can make for a comical situation when adults gather in a classroom. Another characteristic of classrooms are the learning tools: crayons and paper, posters and chalkboards, large calendars, and pencil sharpeners. Many teachers organize materials so they are available at the instant they are needed and there are enough for every person.

Is there only one correct way to organize the classroom: the furniture, the schedule, the climate, and the books? No, there are hundreds of arrangements that could promote an effective learning environment. Teachers are constrained by the desks the school provides, the types of educational materials the board of education adopts, and the size and shape of the room. And yet, teachers have immense influence over the classroom, especially when we take into account the features of a classroom that we would describe to an anthropologist. In short, the culture of the classroom is one of its most defining aspects.

A dozen teachers provided with identical materials for use in the exact same space would, not surprisingly, create different classroom cultures. The classroom culture is partially an extension of the teacher: his or her views about the purposes of education, his or her own experiences as a student, and his or her beliefs about the ways to help children learn. The classroom's culture also reflects the students in this room. Just as the teacher brings his or her background into work, so do the children. The ideals of the students, their ways of communicating, their personal aspirations, and the need to define themselves as members of society all contribute to the classroom culture that is formed.

Not only is the classroom culture the by-product of the personalities of those present but it is also an ever-evolving entity. We would expect a classroom to change from the first day of school to two months later. In more subtle ways, the classroom would be perceptibly different at the start of the school day and partway through. The physical arrangement of the students (doing independent writing versus participating in a whole group discussion), the kinds of tools being used (watching a video versus working with manipulatives), and the general tone of voices (teacher giving directions as the class prepares to leave the room versus children telling each other about their favorite music) are all examples of shifts in the classroom culture. Altogether, these features and many others define a culture. Classrooms are a type of culture, and it can be enlightening to consider what teachers might do to define and sculpt a classroom so it becomes an environment supportive of everyone's learning. Classroom culture signals the science learning opportunities made available to students.

The Boundaries of a Culture

A culture is described by the traditions of a group of people. Individuals sharing a culture have a common language, common clothing styles, favored foods, and music preferences. There are certain routines distinguishing a group, such as the holidays that are celebrated, the ideas that are honored, and other features that bind and unify them as a group. The forces causing some individuals to hold higher status than others within a culture are yet another cultural artifact. These sorts of power relationships also define who is included and who is excluded from a culture. You cannot simply join a new culture because you want to. To become a member of a culture, you must be able to function within the norms of that culture, and your ability to demonstrate your understanding of those norms will determine your acceptance by the culture.

When people refer to a cultural group, they often think about a nationality and all the stuff associated with the culture (styles of communicating, ways of dressing, types of food). A person who is born and raised within a city in Taiwan is a member of a culture that is very different from that of someone who grew up within a Navajo community. If we would bring together persons from these two cultures, they would not automatically understand each other for reasons that go beyond language differences. A substantive difference between the two people would be the ways they interact with other people within their culture. Another difference would be their ways of engaging in worship. Individuals from the two cultures might legitimately feel their own ways are normal and that the traditions of the other person are odd.

We might anticipate that a child would be proud of his or her culture. This child would see that the person he or she is becoming is an extension of the cultural traditions of the family and community. Certainly, cultures change over time as new words are invented and new tools become incorporated into the culture. But we hope that a child would not be taught to believe that other cultures are automatically odd, inferior, or wrong. Instead, we expect that people would come to accept other cultures. We feel most comfortable and natural when we function within our own culture, and we expect that others will respect our culture for that very reason.

Membership in Multiple Cultures

Up to this point, we've associated cultures with nationalities. This doesn't mean just geographic boundaries because someone can be a member of a culture even when he or she moves beyond the national borders. We wouldn't expect someone to stop being Senegalese or Turkish just because he or she traveled outside of their country. Being a member of a culture involves much more than simply where you live.

Most of us are members of more than one culture. This statement requires us to recognize that culture has a more specific definition than one's nationality. Imagine a group of friends who share certain music preferences, enjoy special types of food and beverages, have particular words or phrases they use all the time, and share a relatively similar type of clothing. We could describe this circle of friends as a cultural group.

If a culture is defined by a collection of shared and accepted traditions, then we can begin to recognize the incredible variety of cultures that exist. A group of women who meet to play cards and socialize represent a culture. Forest firefighters who work, eat, and live together throughout the fire season are a culture. People who gather online to discuss their lives and fears are also a culture. In each instance, characteristics define the culture, such as ways of communicating and interacting. Someone who is not a member of a certain culture has a hard time understanding the vocabulary or recognizing the acceptable ways of behaving. He or she would probably feel awkward trying to fit in. But over time, a new person might begin to get the hang of the abbreviations that are used in the chat room or the significance of the bids made in the card game. Over time, the person might learn enough of the cultural norms to become accepted into that culture.

Perhaps you are contemplating the cultures with which you are associated. Anytime you join a group with which you develop specific ways of thinking or acting, you become a member of a new culture. These groups might be found at school, church, or work. If you have a job, then you know there are certain words and phrases one needs to know. In addition, there are certain ways in which things are done, whether it's how to answer the phone or how to arrange the utensils on the table. You may have different ways of acting when you are in the role of a student. An important part about learning to become a teacher is developing skills at functioning within the culture of teaching.

A Broader View of Culture

A cultural group is defined by its traditions. We might stretch our definition of culture and use it to talk about cliques. Often a group of children from widely varied family backgrounds will have a common passion for a certain artist or author, and that shared interest will come to define who is in their group and who is not—this could be appropriately identified as a cultural group. Professions also act to define cultural groups. Nurses can be thought of as a cultural group, as can bus drivers, bank tellers, and bartenders. Even though members of these groups may all speak English and live in the same town, features of their work lives distinguish them from other professionals: accepted attire, the hours they work, the equipment they use, and the ways they communicate.

> A clique, a club, a gang, the prisoners in a jail, provide educative environments … as truly as a church, a labor union, a business partnership, or a political party. Each of them is a mode of associated or community life, quite as much as is a family, a town, or a state. The activity of each member is directly modified by knowledge of what others are doing.
>
> (Dewey, 1916/1944, p. 82)

People learn to be members of a cultural group. If you grew up with others who had a shared set of religious beliefs, then you learned about that religion by being associated with others who were practicing it. In this regard, a culture becomes a force that can educate its members, also expressed by John Dewey.

One purpose of education is to guide students to be able to learn to think about their world in many different ways. Although it's an oversimplification, we could think about the school curriculum as a collection of appreciation courses. Students cannot be realistically expected to learn all the content in science, history, music, economics, math, sports, and so on. But we would like for them to develop a taste for all of these. If we wanted to design a curriculum that used subject-area appreciation as a guiding principle, what sorts of learning would occur? Obviously, we wouldn't be satisfied with having the students memorize terms associated with every subject area. Instead, we would want the students to experience these subjects in ways paralleling the ways that professionals enact them. Our curriculum would require a thoughtful combination of concepts (the "nouns") and skills (the "verbs"). For art, this would mean learning some color theory and some painting techniques. For math, this would be learning shapes and how to solve problems. Let's consider how this might apply to science.

The objects and actions of a culture should parallel the concepts and skills of an academic field. Art and math might share an interest in shapes, but the way that artists and mathematicians approach their subjects is quite different. Learning to become a skilled member of a culture includes recognizing and using the tools and objects of that culture. Cultural objects include boomerangs, kayaks, and weaving looms; we can add Bunsen burners, magnifiers, and thermometers—just to reinforce that the scientific culture has its unique objects. What is maybe less obvious to you, and perhaps entirely unfamiliar to your future students, is an appreciation of the cultural aspects of science. This is perhaps why the idea of studying (or teaching) science makes so many people uncomfortable. When you aren't sure about the proper etiquette of a different country, you're naturally concerned about making a major mistake (or, if in France, a *faux pas*). But if someone familiar with the culture educates you about the proper way to think and behave, then your comfort level rapidly rises. This same diplomacy is useful when teaching science. To help students become comfortable and proficient within the culture of science, you can serve as their tour guide. You could imagine science teaching as the task of introducing a group of students to this culture by providing them with terms, skills, and thought processes that will permit them to participate within the culture. In what follows, we will provide information about important actions within the science culture.

Science as a Culture for Students

Perhaps the closest you've been to learning about the actions of science before college occurred when a teacher encouraged you and your classmates to "think like scientists"—and you were left to imagine how to go about doing such a thing. Our position is that learning the culture of science should not be left to students to figure out for themselves. Instead, their teacher must make the traditions clear, acting as if he or she is a cultural emissary for science. Our list of scientific habits of mind is a reasonable starting point. Curiosity, openness, and skepticism are traits we can define for students and encourage them to use as they do science. A teacher is doing a much better job by telling the class "As we discuss this activity, I would like for you to practice your skepticism" rather than saying: "Use your scientific minds." Making the subtle features of the science culture obvious to students removes the guesswork.

Imagine how much easier it would be if, when faced with a new setting, the cultural traditions were made perfectly clear. Having someone willing to explain the traditions would make you more comfortable and allow you to navigate within the culture. Consider the common cross-cultural misunderstanding of physical proximity. In some situations, an individual may feel as if his or her personal space is being violated by the closeness, if not actual physical contact, that members of another culture initiate. In contrast, an individual might perceive a culture as being too remote and cold because others don't greet each other warmly or embrace when they meet or even maintain eye contact during conversation. Think about your willingness to engage with members of another culture. Having a complete knowledge of another culture would provide you with a greater sense of being able to regulate your actions and the ways others perceive you. You would feel competent, and there would be very few occasions of awkwardness—all because you understand the objects and actions of the culture.

We are suggesting this is the same disposition when teaching science. Teachers of science can serve as ambassadors who guide students to understand the norms and expectations of the science culture. Rather than expect students to absorb the culture of science by being immersed in it, a teacher can support students by providing unambiguous information about the cultural objects and actions. There is no single approach that will accomplish this. A skillful tour guide will be on the lookout for examples to illustrate the points he or she wants to make. Likewise, when teaching science, the teacher should be attentive to opportunities to highlight habits of mind unique to the science culture. One might say that the goal of science teaching is to communicate the source of power to students so they can become confident as they move about within the culture of science. By being more explicit about the cultural norms of science, the teacher can guide students to know when and how to act in ways appropriate to that culture.

Science is not a subject that attracts a sufficiently diverse range of individuals. Our hunch is that the dynamism of science has not been made explicit to students. The objects and actions of science, which represent the **culture of science**, may feel too unchanging to appeal to many students. Increasing students' interest in science and their confidence in their abilities requires teachers providing them with a better sense of the culture of science. The habits of mind we have introduced are just one component. There are additional actions of the science culture, including inquiry and the nature of science, which you will encounter in subsequent chapters. But for right now, we want to introduce the idea of the actions of science and explain how this is fundamental to learning science.

We can create a considerable mess if certain cultures are presumed to be superior to others. This applies especially when helping students make the connections between their home cultures and the culture of science. We advocate for classrooms that create a healthy and respectful balance between the culture of science and the cultures of the students (Aikenhead, 2000). Science, for all its marvelous accomplishments, has its limitations. There are questions we might ask that science is unable to answer. If you've heard about multiple intelligences, then you are aware there are many ways of being "smart." You can have musical smarts, interpersonal relationships smarts, athletic smarts, and so on. Scientific smarts cannot substitute for these other types of intelligences because thinking in a scientific way is constrained by the need for data.

A Deep and Systemic Look

Today's classrooms are not homogeneous places. The very dynamics that are changing the nation (i.e., economics, politics, globalization, climate change, and so on) are influencing schools. Altered economic conditions, shifting demographics, and revisions to legislation have brought students who have a wide variety of ethnic backgrounds, socioeconomic conditions, primary languages, and behavioral and cognitive abilities. One thing that is certain is that this variety, this heterogeneity, will continue as features of public education throughout your teaching career.

Teaching science in ways that are effective for a diverse student population obliges us to reconsider unexamined assumptions. In addition, having the belief that all children are capable of learning science is essential. The "ordinary" teacher has tremendous opportunities, if not the duty, to make this happen. One step toward this goal is to regard science as a culture. Adopting a perspective of science as a culture implies that teachers must become skilled at doing science, but students must also be provided with access to the scientific culture. The scientific worldview will seem more familiar to some students and stranger to others. For many students from non-Western, non-European backgrounds, the culture of science can seem foreign and frightening. Understanding the cultural aspects of science encompasses learning about the actions (ways of thinking and inquiring) and objects (physical tools, such as microscopes and graph paper), and science concepts such as gravity. We can learn about a culture by reading stories or watching videos; learning to function in that culture can only occur by participating in it while being coached about the norms regarding objects and actions. Only by making science a clearly human pursuit can we expect a wider variety of students to willingly engage in it. The benefits of such a shift extend beyond issues of mere motivation. Interest translates into persistence, which in turn promotes heightened self-confidence. These are powerful foundations on which a teacher can build a science teaching agenda that opens students to a wide array of life's options.

Chapter Summary

- Students can develop more positive views about their scientific capabilities when scientist stereotypes are replaced with a cultural view of science.
- Thinking in a scientific manner draws on multiple mental habits that distinguish it from other ways people understand the world. These habits of mind include having curiosity and skepticism and being open to new ideas.

- Three-dimensional science learning refers to the necessary interweaving of three components, core ideas, scientific practices, and crosscutting concepts, required for the development of science proficiency.
- Science proficiency centers on the students' ability to thoughtfully and productively participate in the activities of science. Although science education was once seen as a way to supply the future scientist pipeline, the current goal is viewed as "science for all." This "all" includes every student who attends school and does not exclude participation in science because of gender, native language, cultural background, physical impairment, or cognitive ability.
- Discriminatory practices of the past, such as excluding women, people of color, and special needs populations, still reveal themselves in science achievement. Even though our path to overcoming these inequities is not completely clear, we recognize that teacher expectations have the potential for reversing these tendencies.
- A cultural perspective can provide science teachers with a fresh way to think about the subject and their role in helping students learn it. Teachers and students can develop more refined and generous views about culture, which include recognizing cultural influences on their individual perspectives.
- As with all cultures, science is distinguished by its objects and actions. The goal of scientific literacy requires having students become participants within the science culture.
- Classroom teachers can serve as cultural ambassadors as they support students in moving in and out of the scientific culture but without discarding the cultural heritage from their families and communities.

Key Terms

Achievement gap: typically the difference in test performance of students in different demographic groups. The persistent gaps between White and Black students have troubled educators because they suggests students are not being provided equal opportunities to become science proficient.

Actions (of a culture): the ways in which participants in the social group think and interact with each other.

Culture: the shared views of a group of people about their values and traditions, united by a common language, physical location, shared history, or belief system.

Culture of science: includes both the objects of the culture (its physical tools and accumulated knowledge) and the actions of the culture (the commonly held patterns of thought and patterns of behavior).

Deficit mentality: the inaccurate belief that many learners come to school without the prerequisite skills, knowledge, and abilities needed to learn science and that until deficiencies are corrected in the learner or the learner's life, then academic learning is not possible.

Objects (of a culture): the physical tools and knowledge that accompanies those tools shared by a social group.

Scientific habits of mind: the values of science that influence the way in which individuals participating in the culture of science think and act. Components of this value system include curiosity, openness to new ideas, and skepticism. A wide variety of emotions that are intimately tied to scientific pursuits accompanies this value system.

Science proficiency: centers on the students' ability to thoughtfully and productively engage in the activities of science and requires that students view science as a body of knowledge and an evidence-based model and theory-building enterprise that continually extends, refines, and revises knowledge. Proficiency in science expands career options, advances the intelligence of the voting public, and gives individuals the resources to make informed decisions as voters and in their daily lives.

Self-fulfilling prophecy: the prevalent pattern throughout all of education that says if teachers expect students to be high or low achievers, students then act in ways that will cause this expectation to become a reality.

Skepticism: the expression of doubt or caution about a claim, often accompanied by a desire for more facts and stronger evidence.

Suggested Readings

Melber, L. M. (2003). True tales of science. *Science and Children*, *37*(7), 24–27.

This article describes going directly to the sources to obtain an accurate view of the work of scientists. Through a variety of nonfiction books, students can read entries scientists made in their notebooks and journals as they went about their research. The benefits of this strategy is that a teacher doesn't have to rely on what he or she has to say about what scientists do—students can learn this information directly through nonfiction texts written by scientists.

Engblom-Bradley, C., & Reyes, M. E. (2004). Exploring native science. *Science and Children*, *41*(7), 25–29.

During a summer camp experience, students learned about the connections between science and Native Alaskan cultural traditions. One example of such integration was an experiment comparing the insulation of wolf fur with that of caribou fur. Students gathered data and interpreted them to show that caribou fur is the superior insulator.

References

Aikenhead, G. (2000). Renegotiating the culture of school science. In R. Millar, J. Leach, & J. Osborne (Eds.), *Improving science education: The contribution of research* (pp. 245–264). Buckingham, UK: Open University Press.

Andrzejewski, C. E., Davis, H. A., Bruening, P. S., & Poirier, R. R. (2016). Can a self-regulated strategy intervention close the achievement gap? Exploring a classroom-based intervention in 9th grade earth science. *Learning and Individual Differences*, *49*, 85–99.

Bell, P., Lewenstein, B., Shouse, A.W., & Feder, M.A. (2009). *Learning science in informal environments: People, places, and pursuits*. Washington, DC: National Research Council.

Dewey, J. (1910). *How we think*. Boston, MA: D.C. Heath & Co.

Dewey, J. (1916/1944). *Democracy and education*. New York: Free Press (Original work published 1916).

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K*-8. Washington, DC: National Academies Press.

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education*, *92*(3), 404–423.

Gay, G. (2000). *Culturally responsive teaching: Theory, research, and practice*. New York: Teachers College Press.

Good, T. L., & Brophy, J. E. (1994). *Looking into classrooms* (6th ed.). New York: Hill.

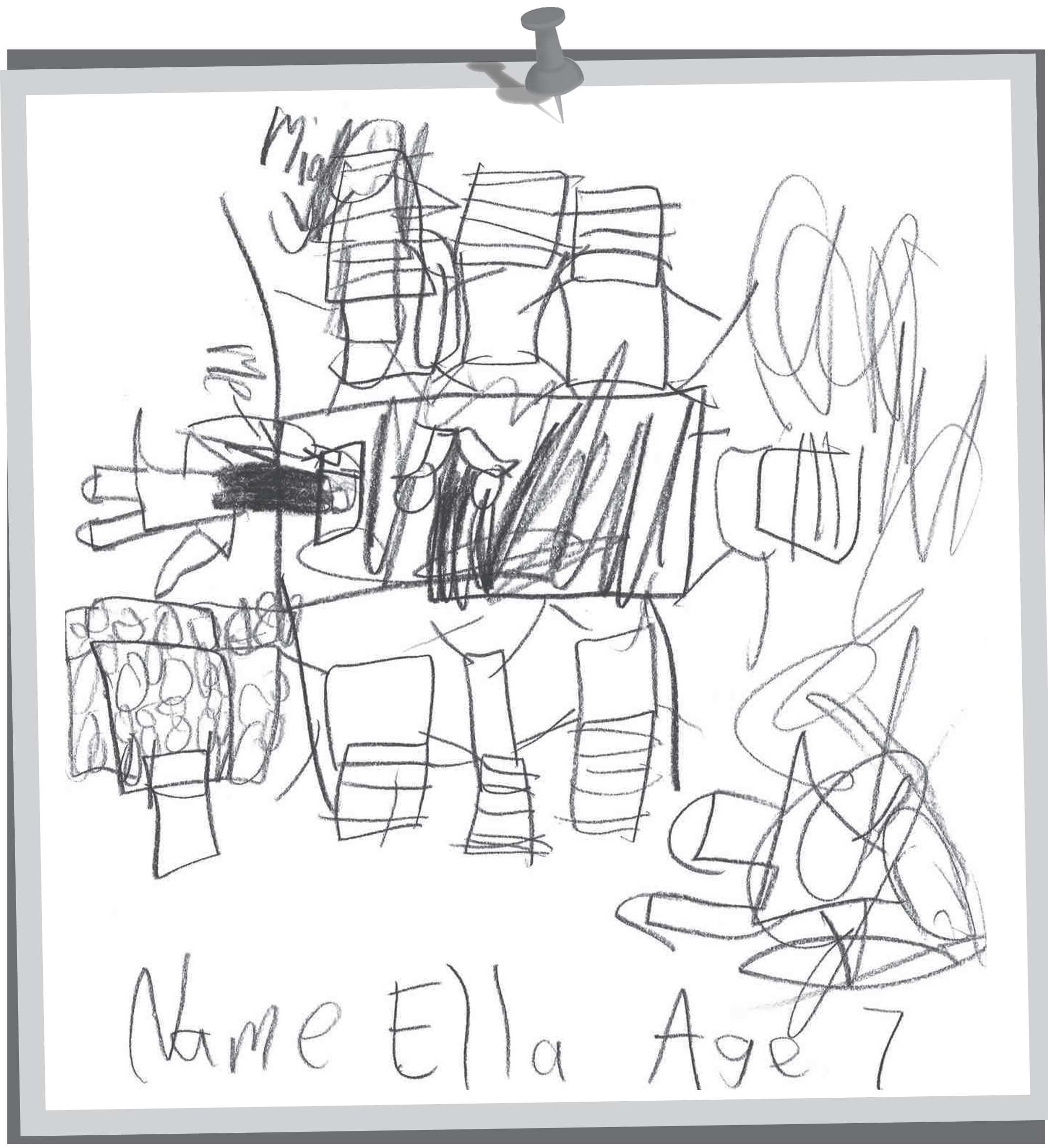
Hawkins, D. (1965). Messing about in science. *Science and Children*, *2*(5), 5–9.

Jaber, L., & Hammer, D. (2016). Engaging in science: A feeling for the discipline. *Journal of the Learning Sciences*, *25*, 156–202.

Krajcik, J., Codere, S., Dahsah, C., Bayer, R., & Mun, K. (2014). Planning instruction to meet the intent of the Next Generation Science Standards. *Journal of Science Teacher Education*, *25*(2), 157–175.

Labaree, D. F. (2010). *Someone has to fail: The zero-sum game of public schooling*. Cambridge, MA: Harvard University Press.

Lynch, S. J. (2000). *Equity and science education reform*. Mahwah, NJ: Lawrence Erlbaum.
Merton, R. (1948). The self-fulfilling prophecy. *Antioch Review*, *8*, 193–210.
Milner, H. R. (2012). Beyond a test score: Explaining opportunity gaps in educational practice. *Journal of Black Studies*, *43*(6), 693–718.
National Academies for Sciences, Engineering, and Medicine. (2015). *Science teachers learning: Enhancing opportunities*. Washington, DC: National Academies Press.
National Center for Education Statistics. (2015). *The nation's report card: Science Assessment*. Washington, DC: U.S. Department of Education. www.nationsreportcard.gov/science_2015.
National Center for Educational Statistics (2016). *Digest of education statistics* (NCES 2016–006). Washington, DC: Institute of Education Sciences, U.S. Department of Education.
National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.
National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Committee on a conceptual framework for new K-12 science education standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
National Science Foundation. (1994). *Women, minorities, and persons with disabilities in science and engineering*. Arlington, VA: Author.
Newkirk, T. (2005, October 12). Brain research: A call for skepticism. *Education Week*, *25*(7), 15.
Nieto, S. (1992). *Affirming diversity: The sociopolitical context of multicultural education*. New York: Longman.
Passmore, C. (2014). *Implementing the Next Generation Science Standards: How your classroom is framed is as important as what you do in it*. NSTA Blog. http://nstacommunities.org/blog/2014/11/10/implementing-the-next-generation-science-standards-how-your-classroom-is-framed-is-as-important-as-what-you-do-in-it.
Standage, T. (2014). *The Victorian Internet: The remarkable story of the telegraph and the nineteenth century's on-line pioneers*. New York: Bloomsbury.
Workman, E. (2012). Teacher expectations of students: A self-fulfilling prophecy? *The Progress of Educational Reform*, *13*(6). www.ecs.org/clearinghouse/01/05/51/10551.pdf.


Name Ella Age 7

two

Nature of Science

Seeing Science from a Bird's Eye View

Chapter Highlights

- The nature of science is central to the scientific culture. Awareness of the nature of science helps students gain access to science.
- Science is a distinctive way of knowing that requires evidence to support knowledge claims. Other worldviews may not require such an emphasis on empiricism. Recognizing this is a valuable realization about the nature of science.
- Creativity is just as essential to science as it is to other ways of knowing. Students can be creative in science as they develop multiple ways to observe, interpret findings, and propose explanations.
- Scientists endeavor to identify the opinions and biases that can influence their observations and explanations. Prior knowledge can help us make sense of what is taking place, but it also places constraints on our thought processes.
- Even though it is a prevalent idea in textbooks and classrooms, there is no singular scientific method. Although certain actions are characteristic of people doing science, it is improper to believe that science proceeds by a fixed sequence of steps that culminates with scientific truth.
- Collaboration by students in their science learning echoes the social nature of practicing scientists. Just as professional scientists do, students should present their work and ideas to others as part of the science community.
- Scientific explanations are tentative and open to revision if sufficient evidence or arguments can be provided. Scientific knowledge advances as old ideas are replaced by better explanations. In a similar way, students' initial ideas can be replaced with more scientifically acceptable explanations.

> Scientists and science teachers agree that science is a way of explaining the natural world. In common parlance, science is both a set of practices and the historical accumulation of knowledge. An essential part of science education is learning science and engineering practices and developing knowledge of the concepts that are foundational to science disciplines. Further, students should develop an understanding of the enterprise of science as a whole—the wondering, investigating, questioning, data collecting and analyzing.
>
> (NGSS, Appendix H)

Too often, science is viewed as a fixed body of somewhat obscure knowledge. For example, many of us have seen the Periodic Table but perhaps have not seen its usefulness. Insiders to the culture of science recognize that the Periodic Table is not only a clever way of organizing all the elements but is also the by-product of centuries of debate. In addition, the Periodic Table continues to undergo change. Four new "superheavy" elements were added in 2015 (elements 113, 115, 117, and 118), completing the 7th period in the Periodic Table. This example may not be a topic of a conventional lunchtime conversation and probably is not relevant to the students at your field placement site. But this example alerts us to the ever-changing aspect of science.

Like all other cultures, science is defined by its objects and actions. In addition, few cultures are fixed and unchanging. Instead, a culture can shift over the years in response to adjustments as old members move along and new members come in to the group. This is all to say that to appreciate science as a culture requires recognizing that science, despite its distinctive features, is in continuous flux—both in terms of *what* we know (as the Periodic Table example shows) and *how* we have come to know it. The **nature of science** is a phrase referring to both actions of science and the characteristics of the knowledge produced through these actions. We think of it as a "bird's eye" view of science—the broadest perspective one holds onto even if details become blurred.

Understanding the discipline you are teaching has always been important. With the recent shift toward three-dimensional science learning as described by the *Framework for K-12 Science Education*, knowing the nature of science is increasingly relevant. As described in the *Framework*, the classroom teacher is expected to engage students in authentic disciplinary activity—that is to involve them in *doing science*. Through active participation, students develop their abilities to participate in the practices of science and hone their knowledge about the ideas and concepts of science (i.e., become proficient in science). For this to happen, teachers possess a strong grasp about the nature of science in order to understand science as a broad "enterprise" to use the quote from the NGSS. Providing that "bird's eye" view, that portrait of science as an enterprise, is the focus of this chapter.

What Is the Nature of Science?

We often face a flurry of seemingly contradictory information. For example, here are actual scientific statements related to nutrition: "A low-carbohydrate diet helps you lose weight and control cholesterol levels"; "A low-carbohydrate diet is unsafe because it is often high in fat and places too much stress on the kidneys"; "Eat high amounts of grains and fruits and a minimum of meats and dairy for a well-balanced diet"; and "Eat a limited amount of grains and a high amount of meats and other protein for a well-balanced diet." How can scientists produce these contradictory messages? Isn't there some mechanism for resolving these contradictions? Shouldn't scientists all say the same things? These questions and contradictory messages are evidence that scientific knowledge about nutrition is being developed; the community has not reached even a tentative consensus on what constitutes a healthy diet. The goal of this chapter is to examine how scientific knowledge is produced, and knowledge production is at the core of the nature of science. A deepened understanding of the nature of science by a teacher will shape how science is taught in the classroom. This in turn will benefit the students: their appreciation for science will be more accurate, and their perceived opportunities to participate in science will be greater.

The phrase **nature of science** describes actions of scientists (as individuals and as part of a larger cultural group), and the underlying tendencies and unspoken assumptions that guide those actions. The actions scientists engage in as part of their work culminates in knowledge that retains these embedded characteristics. It is as difficult to list the components of the nature of science just as it is challenging to summarize the parts of any culture. It is unwise to reduce any group of students to a list of specific characteristics (e.g., girls like to work in groups, children with disabilities don't like to be singled out, English language learners will need particular help in the sciences) because there is so much individual variation among group members. Likewise, it is challenging to reduce the nature of science to an accurate list of characteristics. So why should we try? Think about it this way: if you were trying to explain your cultural traditions to outsiders, you would need to help them recognize major features of your culture. Knowing the timing of special events, the kinds of food that are eaten, and special phrases that are used are only surface features. A genuine cultural tradition consists of much more than its rituals.

Traditions have their bases in underlying beliefs. When outsiders simply attend to surface feature of a culture, they fail to recognize the significance of those traditions to the members of the culture. To study science without an understanding of the nature of science is to become familiar with simplistic dimensions but never fully understand, be comfortable with, or work within the culture of science. Our goal for this chapter is to provide you with a sense for what is included within the nature of science as an important step toward understanding what is meant by the culture of science. The short-term goal is strengthening your understandings of the nature of science in ways that will make that knowledge more functional. **Functional knowledge** describes information and skills that allow you to skillfully engage in particular activities. A functional knowledge of science would be evident by someone adept at participating in science. The long-term goal is for you to use this knowledge to design meaningful science experiences for your students.

Unpacking Students' Ideas about the Nature of Science

When we ask students, "What is science?" we often receive the same sorts of responses whether they are elementary school, middle school, high school, or college students. Students point to a biology book and say, "That is science." Or they may give a list courses; geology, physics, biology, and chemistry. With additional probing, they'll cite the scientific method as the way science is done. As we spend even more time discussing these matters, students (again from across the age and grade spectrums) explain that science is a large body of very sure facts, facts that are "discovered" by objective scientists as they study all aspects of the world, a study that is sometimes described as "prying open" the natural world as if the answers are hidden inside like a prize. These scientists are often viewed as "lone rangers" who work in isolation and surprise the world with their discoveries after long hours of diligent work.

> **For Reflection and Discussion**
>
> If you were asked to draw or describe a scientist without thinking about it too deeply, what characteristics would you include? If elementary or middle school students held the same views of scientists, how might that influence their desire to become participants in that culture?

How do we develop our ideas about science and scientists? It is notable that students' responses are very similar across ages. This suggests that these ideas are first learned early in life and that little occurs to alter these perceptions. Elementary schooling might contribute to this situation. Unfortunately, not many students actually participate in science while in elementary school. So where do these ideas come from? It seems that much of what students "know" about the culture of science comes from the media—the news, movies, cartoons, and so on. Think about the scientists you've seen on television and in movies, fictional stories, and educational programs. What do these scientists have in common? They are usually seen as White men with wild hair who are just a bit different from all the others around them. Even programs supported by the National Science Foundation for educational purposes, such as *Bill Nye the Science Guy,* can reinforce such stereotypes.

Few accurate portrayals of science, as performed by actual scientists, are available to most of us. The stereotypical versions of science, although comical, send a clear message to students that only certain people can become scientists. These misperceptions of science may actually cause students to believe that science is not something they can do or would want to do. Our working hypothesis is that if students' mythical notions are examined, if we can help teachers and students to understand the actual nature of science and scientific inquiry and who does it, then more students will understand that they can be capable science learners.

Students will enter their formal studies of science class holding many perceptions about the nature of science. In the following section, we will describe actions of science through a discussion of the spheres of scientific activity. Following this, we will examine the characteristic of the knowledge produced through those actions—at least the most relevant aspects of the nature of scientific inquiry for elementary and middle school students. As we examine the nature of science concepts, we point out the common myths held by students (and far too many people from the general public). Next, we address the aspect of the nature of science that may be the most pertinent for effectively teaching science in a diverse setting. Finally, we will circle back to the central role the nature of science plays in three-dimensional science learning.

Characterizing the Actions of Science: Spheres of Activity and the Mangle of Practice

The actions of science include: (a) the tasks of collecting information (data or evidence) about the world and (b) the objects of science, which are the explanations that scientists construct to make sense of that world. One defining feature of the actions of science is that they center on a process of inquiring into the physical world. Passmore (2014) describes these actions as what we do to "figure things out." That is, at some level, the actions of science can never stray too far from the world surrounding us or from our questions about it. But neither can it stray from the