Being and Becoming Scientists Today
Reconstructing Assumptions about Science and Science Education to Reclaim a Learner–Scientist Perspective
Susan A. Kirch and Michele Amoroso
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Research Dialogs consists of books written for undergraduate and graduate students of science education, teachers, parents, policy makers, and the public at large. Research dialogs bridge theory, research, and the practice of science education. Books in the series focus on what we know about key topics in science education— including, teaching, connecting the learning of science to the culture of students, emotions and the learning of science, labs, field trips, involving parents, science and everyday life, scientific literacy, including the latest technologies to facilitate science learning, expanding the roles of students, after school programs, museums and science, doing dissections, etc.
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Reconstructing Assumptions about Science and Science Education to Reclaim a Learner–Scientist Perspective

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In loving memory of Geraldine Chapman Kirch (1941–2012) who was proud to call her daughter a scientist.

To my wonderful parents Joe and Angie Amoroso, who inspire me to reach for the moon and smell the roses along the way.
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INTRODUCTION

As the title suggests, this book is about teaching science from a learner or what we will call a learner–scientist perspective. It presents an approach to being aware and mindful of learner questions, puzzlements, wonderings, motives, goals, and experiences. In order to teach from a learner perspective we must necessarily challenge assumptions about science and science education and we must reconstruct what it means to be and become a scientist. For example, what do we mean when we talk about “scientists”? In this book, we are referring to a person who is interested in understanding the natural world and questioning the status quo by using, modifying, and creating tools for thinking critically and scientifically—tools such as questions, explanations, facts, ideas, laws, concepts, theories, schema, rules, norms, social practices, skills, and even algorithms. In this book, scientists are not limited to people who are certified career scientists, but include citizen scientists, science enthusiasts, science educators, and science learners of all ages and from all walks of life. Broadening more traditional definitions of scientist is not a new idea (especially for elementary school science teachers), but it has been an uphill battle since the word was widely adopted in the late 1800s. Just saying everyone is or can be a scientist isn’t adequate to ensure everyone can learn to be a scientist. In fact the assertion, everyone is or can be a scientist, often faces many contradictory practices and assumptions in science education.

First, science education, as an enterprise, presents science from a disciplinary perspective rather than from a learner perspective. This means that learners are viewed as people who need to learn (1) canonical explanations of the world, (2) specific methods of investigation, and (3) the norms and schema for knowledge production accepted by various scientific disciplines. These top-down directives are rarely coupled with the bottom-up motivation of the learner who doesn’t understand why she is being told to learn these explanations, methods, and norms of knowledge production. How can science educators reclaim a learner perspective and position students as the primary agents in control of their own learning activities such that they see purpose and meaning in these aspects of science (knowledge, methods, norms) deemed important by the enterprise?

Second, the notion of a scientist usually reflects either a historically famous scientist (e.g., Einstein, Carson, Curie, Newton) or a fictional career scientist who, according to classroom teachers: “works hard,” “is very smart,” “observes carefully,” “takes good notes in his notebook,” “waits to talk,” “sits quietly,” “uses evidence to back up her claims,” and “uses the right science words.” These portraits of scientists might be appealing to some students, but others might be intimidated, uninterested or discouraged. As we know, the students in the latter category often start to think they are not good at science or that science is not for them. How can science educators
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change the images of scientists we create (consciously or unconsciously) and teach in a way that supports students as already being scientists?

Third, not only is science presented as a career field that recruits and employs gifted and talented individuals, it is also presented as a static body of knowledge, an anonymous, authoritative industry, and a standardized process of describing and explaining how the world works. As a result, learners see scientific knowledge as facts to be remembered or memorized rather than as tools and knowledge-actions people can create in collaborative transformative practices for self- and community development. How can science educators rethink how we conceptualize contributions to science to be more inclusive of young people who are eager to learn and be what Joe Kincheloe and Shirley Steinberg (1998) refer to as “players” in the world?

Fourth, another difficulty with adopting a disciplinary perspective of science is how scientific problems are presented. This is related to the second problem. The lack of social, cultural, and historical contexts in science education often results in the absence of any connection between knowledge production and a human story. Alternatively, a focus on famous or genius scientists leads to a single story of knowledge production. How can science educators represent scientific problems and tools for thinking in a way that encourages students to expect and seek out the multiple stories of scientific knowledge production and see themselves in these stories now and in the future?

Finally, students are rarely put in the position of authentic researchers. We believe this is primarily because it feels disingenuous to ask students to rediscover a canon of basic science concepts listed in our school’s science standards for learning. For example, asking students to research how things move in order to reinvent Newton’s laws of motion through inquiry is not a trivial instructional goal. More often than not, it ends with teachers telling students the so-called right answer when students fail to replicate classroom investigations in a way that demonstrates each of the laws (which, in the case of Newton’s laws of motion, cannot be replicated in the classroom or laboratory because they are idealized). Most of the concepts and ideas we expect students to learn in science took years of dedicated study by many people and often represent theorized observations and concepts therefore, the form of rediscovery needs to be carefully planned and managed, and there are few tools to help teachers do this. How can we position students as researchers in a way that allows them to lead inquiry projects and free educators to serve as radical listeners and instructional designers?

These are the contradictions and questions we attempt to address in this book.

THE AUDIENCE

This book is intended for elementary school teachers (including generalists, special educators, and science specialists) who want to further develop their own practice and understandings of classroom interactions and develop ways to uncover the
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perspectives of the young learners with whom they work. It is also intended for science teacher educators who want to introduce teacher candidates to tools to help them be and become scientists and radical listeners. Education leaders (principals, supervisors) who are considering new and innovative ways to work with their faculty and staff to evaluate elementary school science program activities may also find this book useful. Finally, parents may find the text helpful in placing elementary science education in a broader social, historical, and cultural context and in providing information necessary to support teachers that want to foster authentic science activity in their classrooms and in children’s homes. Although many of the ideas, conclusions, and recommendations in this book are the result of our work with children approximately 7 to 10 years old, we believe most are appropriate for science learners of all ages (including their teachers).

THE SETTING

We (Sue and Michele) began working together in 2003 and have co-taught or worked in parallel at different schools in New York City since then. We have audiotaped and videotaped hundreds of hours of classroom conversations (small-group and whole-class discussions) and research interviews for review and discourse analysis. Sue conducted research with Michele when Michele was teaching second grade, and has also conducted research with several other classroom teachers (third through fifth grade) since then. The populations of the schools where our research and teaching took place were varied. Our early research took place in a professional development school (grades preK–8) affiliated with a local university. At the time of our co-teaching and research, this school had a diverse student population of approximately 250 individuals (it was a new school that had not yet reached its maximum student capacity). According to census data available at the time, the students categorized themselves on city registration forms as Black (45%), Asian/Pacific Islander (30%), Hispanic (15%), White (10%), and American Indian (1%). Three percent of students were classified English language learners, and 10% of the population was eligible for special education services. According to the principal, 30% of students qualified for free or reduced price lunch. Enrollment was determined by a lottery.

Sue’s most recent work (featured primarily in Chapter 5) took place in a public elementary school classified as Title I eligible. It served children primarily from the surrounding neighborhood, which included a temporary housing facility and a nearby housing development managed by the New York City Housing Authority. Research participants included students (N = 126) and teachers (N = 9) from three fourth-grade classrooms (9–10 years old) and three third-grade classrooms (8–9 years old). Approximately 17% of classroom participants were eligible for special education services and 29% were eligible for English as a second language services, and their predominant language was Chinese (Fukonese or Mandarin). Four general education elementary teachers each led one of four classes, and two classes were
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go-led by two teachers: a general education elementary teacher and an elementary teacher with special education certification. This collaborative team teaching (CTT) model was common practice in the public schools in the district. According to the census data at the time of the study, students categorized themselves as Hispanic (29%), Asian (58%), Black (10%), and White (3%). The majority of students were from low-income families with about 70% qualifying for free lunch.

What is the point of sharing these demographics? Although our classroom experiences may not mirror yours, we would like to claim that the ideas we’ve developed and described here have worked well across these varied populations and with several teacher–researcher partners.

AN OVERVIEW OF THIS BOOK’S ORGANIZATION

In our own practices we have been reconstructing assumptions about science and science education from the perspective of the learner–scientist and have written this book to convey what we have learned so far. In each chapter, we unpack a related set of questions posed from the perspective of young learners based on our research and experience. We attempt to provide a commentary that reflects social, cultural, and historical trends related to questions such as where has elementary school science been, and where might we go? Most important, we present and explore a variety of resources for creating elementary school science teaching and learning environments that respect young learners and honor their eagerness to learn about the world as guided by these questions.

Chapter 1. Rethinking Science Education from a Learner Perspective: A Framework for Being and Becoming Scientists Today (BBST). In this chapter we introduce our framework for science education (BBST) and compare it to the current dominant views of what science learners can and should do. We outline the types of questions learners might be expected to ask as they establish themselves as learner–scientists.

Chapter 2. Being and Becoming Scientists. In this chapter, we address the learner questions: What does it mean to be|become a scientist? Who can be|become a scientist? How do I be|become a scientist? How am I a scientist today?

Chapter 3. Contributing to Science. In this chapter, we consider the learner questions: What is scientific knowledge? How does one contribute to science or scientific knowledge? Could I contribute to science?

Chapter 4. Representing Scientific Problems and Tools for Thinking in Instruction. In this chapter, we consider the Next Generation Science Standards as we explore answers to the learner questions: What kinds of problems do scientists work on? Do I like to work on the problems of science? Would I like to become a scientist?
Chapter 5. Classroom Results from a Knowledge and Knowing Study (KKS). In this chapter, we present a method to engage students in the research questions from learners: How do I know what I know? How do scientists know what they know?

We have organized these chapters around the learner questions proposed in our framework for science education (see Figure I.1 for an overview of the book).

![Figure I.1. A graphic overview of the book's organization](image)

In addition to the five chapters that make up the central body of the book, readers will find we included some additional guidelines and reflections. A section at the end of the book includes a more detailed scholarly autobiography for each of us (Sue and Michele), a reflection on how we met and a brief dialog in response to two questions that arose after we finished writing and began sharing parts of this book with colleagues. We have also provided a glossary for a few key terms used in the book. In the Appendices, we have included the transcription conventions used in all of the transcripts featured throughout the text, as well as templates of several instructional tools for reproduction and classroom use. We are always honored when colleagues find our work useful, and we hope you share this book with many others; when you do, all we ask is that you cite our work even if you modify the tools. Recommended citations are included as part of each tool. Let us know what works for you. We hope you find here many useful resources, ideas, and recommendations to use and share.
CHAPTER 1

RETHINKING SCIENCE EDUCATION FROM A LEARNER PERSPECTIVE

A Framework for Being and Becoming Scientists Today

Education should help one make sense of the world. At the same time it should help students make sense of themselves as “players” in the world. … A good education should prepare students as researchers who can “read the world” in such a way so they not only can understand it but so they can change it. Students as researchers, as we envision them, possess a vision of “what could be” and a set of skills to uncover “what actually is.”

—Kincheloe and Steinberg (1998, p. 2)

Anyone who works with children knows they can be adventurous explorers, curious investigators, astute observers, inference-making “machines,” imaginative arguers, relentless knowledge seekers, creative interpreters, and meticulous note keepers. All these strengths with which students enter school can be further developed through a science education program that supports students as researchers rather than treating them as skill-less novices unable to learn abstract concepts. In this book we aim to present a vision of students as researchers that builds on Kincheloe and Steinberg’s (1998) notion of preparing students who can not only understand the world, but also transform it, and themselves, in the process of learning. When we adopt a learner perspective (which we define shortly) it becomes easier to see learners’ strengths and confusions, but it also becomes more difficult to find instructional resources that address this perspective. While there are plenty of activities students enjoy doing, their purpose is often unclear to students, and over time science is seen as a place where students go to learn and memorize random facts about the world discovered by an anonymous person or a genius they have no hope of emulating. In this chapter we present a new vision for science education, one that positions students as researchers of their world, including what it means to be and become a scientist. First, let’s consider the status quo.

Science Education from a Disciplinary Perspective

It is common for science teacher educators, instructional material developers, and authors of science learning standards to represent science as a three-part structure, including the (1) body of knowledge in science, (2) methods and processes of generating knowledge in science, and (3) ways of knowing in science—or Nature of
Science (NOS) (Figure 1.1). We called this structure the three-legged stool model of science, in accord with the metaphor a stool is stable only if each leg is sturdy. When we first started collaborating and co-teaching, we believed it was necessary students learn and understand each leg to acquire a useful grasp of science.

Figure 1.1. The three-legged stool model of science reflects the perspective of the discipline as viewed from the side of the stool (left graphic) and the top of the stool (right graphic)

We searched for interesting, productive, and efficient ways to bring the three elements together, but students were usually more interested in doing experiments and activities and less interested in reflecting on the body of knowledge (content), methods and processes used in science, and nature of scientific knowledge. Viewing science as these three interconnected but separate domains limits our perception of what learners should do and know as well as how the curriculum should be designed. First, learners are viewed as students who need to learn that scientists use various methods when they do their research. Second, learners are viewed as students who need to learn that scientists explain how the world works. The explanations students need to learn are the canonical explanations scientists use for natural phenomena. Third, learners are viewed as students who need to learn that scientific knowledge has particular characteristics. In keeping with these assumptions about what students should learn in science, many in the field argue that we design instruction in order to “give” students: the methods career scientists use and opportunities to practice these procedures (e.g., inquiry standards); opportunities to learn canonical explanations and explain the world the way career scientists explain it (e.g., content standards); and exercises to explore the nature of scientific knowledge. Examples would include salient features of scientific knowledge and knowledge production based on studies of career scientists (e.g., nature of science standards).
Developers of U.S. science education instructional materials are clearly divided over how we teach these three areas effectively and what is necessary when committed to science for all. As a result, curricular practices in U.S. elementary schools focus on one or two of the domains shown in Figure 1.1 and only rarely address all three domains of the scientific enterprise. For example, much instructional material development focuses on teaching and learning science content and method with little to no attention paid to the nature of scientific knowledge. The recent Framework for Science created by a National Research Council (NRC) Committee states this problem clearly:

Debates over content versus process are not in step with the current views of the nature of science …. Science is seen as a fundamentally social enterprise that is aimed at advancing knowledge through the development of theories and models that have explanatory and predictive power and that are grounded in evidence. In practice this means that content and process are deeply intertwined. (National Research Council [NRC], 2012, p. 127)

In response, the panel that created the Next Generation Science Standards (NGSS) suggested a way to achieve the Framework vision:

The Framework emphasizes that students must have the opportunity to stand back and reflect on how the practices contribute to the accumulation of scientific knowledge. This means, for example, that when students carry out an investigation, develop models, articulate questions, or engage in arguments, they should have opportunities to think about what they have done and why. They should be given opportunities to compare their own approaches to those of other students or professional scientists. Through this kind of reflection they can come to understand the importance of each practice and develop a nuanced appreciation of the nature of science. (Achieve Inc., 2014, p. 7)

The NGSS recommendations are a shift in the right direction. We agree having students reflect on what they have done (and why) and having them compare their approaches to those of others is essential, but it is not enough. What more, then? Our emerging view is students need immediate access to science that engages them as researchers in a manner not provided by the three-legged stool.

In the three-legged stool model, students are exposed to an idealized version of science that ignores, excludes, or rejects their own prior knowledge, methods, and beliefs about the world. When we started working together we were interested in teaching students the notion anyone can become and be a scientist. The stool model of science and its implications for science education, however, proved to be one of the biggest constraints on our early work because it was ubiquitous and imbued with authority from the science and science education communities. Its ubiquity made it difficult to imagine other options, while its authority discouraged any attempt to seek out alternatives. We did escape, however, and based on our work with teachers...
and children over the last decade we developed a concept of science from which we could imagine forms of instruction providing students with immediate access to science and being and becoming (herein, being|becoming) scientists.

**Science Education from a Learner Perspective**

The stool model presupposes the student as an outsider who must master skills and factual content before entering a mature discipline. Our framework proposes science should be represented from the perspective of the learner rather than the perspective of the discipline (Figure 1.2).

![Figure 1.2. The Being and Becoming Scientists Today (BBST) framework for science and science education](image)

We want to be clear at this point that the phrase *a learner perspective* does not refer to observations or ideas about students’ particular interests or opinions (e.g., “Many students this age get excited about dinosaurs and outer space”; “Bella is really interested in how weather forecasting works”; “Aiden has been collecting...
rocks and wants to know how volcanoes work”). In this book the phrase a learner perspective refers to the questions and goals of science learners. It presumes the learner is interested in the world around her and is eager for ways to learn how to learn more about it. The model implicitly acknowledges that a spirit of wonder, and desire to understand and explain, are necessary to sustain scientific inquiry. However, our model does not mean the student must or should arrive at these questions independently or in their own time. What would be the point of being a teacher if we took this passive view of development? Learning can lead development and teachers are catalysts in creating the lessons, resources, community, and norms that make teaching and learning from a learner perspective possible (Vygotsky, 1978). In adopting the framework shown in Figure 1.2, we recognize the goals of any science learner are to learn how to enter the conversation of science now and in the future, conduct inquiry in the pursuit of credible information, and be a scientist. Furthermore, the goals of any science teacher are to design instructional environments and facilitate the transactions that help students accomplish these goals. In light of these goals, we refer to this framework as the Being and Becoming Scientists Today (BBST) framework.

If the learner is thought of as someone being a scientist rather than as someone who should simply reproduce what others know for the sake of reproduction, then the representation of science is different and the questions of science educators change. Instead of posing statements of the discipline (e.g., “Scientists explain how the world works”), we pose the questions of a science learner (e.g., “What kinds of problems do scientists work on?”, “How does one contribute to scientific knowledge and could I see myself doing that?”, “Would I like to become a scientist?”). In Table 1.1 we contrast the current disciplinary perspective of science in the stool model with the perspective of the learner given in the BBST framework to illustrate how the perspectives address the same three areas, but from different standpoints.

We see several differences between these two perspectives when compared this way. The disciplinary perspective (middle column) is top-down and empty of motivations, history, origins, and purpose. The learner perspective (right column) turns away from idealized notions of science and toward a notion of learners being a scientist through being, knowing, and transforming their world. Our framework, based on a learner perspective, still accepts that the experience and understanding of the methods of science is very important for success in science, but further acknowledges the learner must be motivated by questions and problems that make their investigations relevant. These questions include learning about why scientists talk the way they talk, do what they do, and whether students enjoy the work of science. Explanation of how the world works, the body of knowledge, is not denied in our framework either. However, when students learn about the problems that engage scientists they also need to learn what interests them, experience what it feels like to build scientific explanations, and finally, see they too can learn how to do it.
The idealized stool model of science (the disciplinary perspective) often portrays abridged, scrubbed histories about the great scientists of the past (e.g., Isaac Newton, Albert Einstein, Marie Curie, Charles Darwin, Rachel Carson). Rather than being instructive or inspirational, these portrayals might lead students to wonder, “How can I ever live up to that?” Finally, questions of the nature of scientific knowledge are situated at the core of our framework, rather than on the fringe or never covered at all. It is essential students question how they know what they know and how

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<th>Education from perspective of learner</th>
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Table 1.1. Comparison of the core aspects of science (body of knowledge, methods and processes, nature of science) between a discipline perspective and a learner perspective of science education
scientists know what they know because this introspection is at the heart of all learning activity in any disciplinary subject. Next, we compare the two perspectives further using three core aspects of science prominent in the stool model.

**Comparing Disciplinary and Learner Perspectives**

*Content or body of knowledge.* In a science education system that subscribes to the disciplinary perspective (Figure 1.1), much effort is spent designing instructional materials aligned to the content generated by career scientists with the content of school science. In an effort to cover as much as possible and ensure students get it right, science content is typically presented as a stockpile of facts or information stripped of the social, historical, and cultural aspects of its production. From a child’s perspective each bit of content (e.g., concepts, explanations, norms, skills) they are told to learn appears out of nowhere and they come to understand they should take it on faith the content is true because their teacher said so or some anonymous (or famous) person or people of high intelligence and great authority said so. Students focus on memorizing information about the world without understanding why and how it was generated in the first place or why it might be useful to them now. This decontextualized, purposeless information is of little use to the learner who often finds it difficult to recall and apply (Bruner, 1966). It is not too surprising to learn many students learn to respect science, but have little interest in being/becoming scientists (Archer et al., 2010).

Alternatively, in a science education system that subscribes to a learner perspective, content is viewed as a tool for thinking and learning. We elaborate on tools for thinking in Chapter 3, but, briefly, these refer to information, explanations, facts, ideas, laws, concepts, theories, schema, rules, norms, social practices, skills, and algorithms we use to accomplish higher mental functions (e.g., mediated perception, focused attention, deliberate memory, and logical thinking) (Bodrova and Leong, 2007). Part of the process of being/becoming a scientist is the appropriation and transformation of these tools for various purposes aimed at learning about, knowing, and transforming our surroundings and experiences, that is, the world. When children come to understand content as an interconnected framework of tools, they have permission (and might even be expected) to ask and to learn who invented a particular tool and for what purpose. Over time, it should not come as a surprise to students someone can transform the tool for another use or someone might come along and invent a better tool investigators prefer over the previous one. By presenting content as tools for thinking we help learners (and teachers) question their origins, purpose, and utility and see real people interested in explaining how the world works produce all content within some problem context. In Table 1.2, we summarize this alignment of the presentation of content from the two perspectives.
CHAPTER 1

Table 1.2. Conceptualizations of the body of knowledge in science as viewed from disciplinary and learner perspectives

<table>
<thead>
<tr>
<th>Discipline perspective</th>
<th>Learner perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decontextualized</td>
<td>Contextualized</td>
</tr>
<tr>
<td>Unquestioned</td>
<td>Able to be questioned</td>
</tr>
<tr>
<td>Imbued with authority</td>
<td>Authority is earned</td>
</tr>
<tr>
<td>Final/unchanging/absolute</td>
<td>Contingent</td>
</tr>
<tr>
<td>Stockpile of facts</td>
<td>Tools</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Human production</td>
</tr>
<tr>
<td>Right/correct/only answer</td>
<td>Answers of varying utility</td>
</tr>
<tr>
<td>True/trustworthy</td>
<td>Credibility</td>
</tr>
<tr>
<td>Purposeless/unclear purpose</td>
<td>Contains purpose, but can be transformed</td>
</tr>
</tbody>
</table>

Method and process. When learners experience school science taught from a disciplinary perspective, the processes and methods they use every day (e.g., observing, describing, predicting, inferring, arguing, and explaining) are taught as if they are something new and foreign. They learn these familiar actions must be coordinated in a particular sequence called “The Scientific Method,” which means hypotheses come before observations, which come before data collection, which come before inferences and interpretations, which come before conclusions and explanations, and may or may not end with new hypotheses to test. It is usually not clear to students why this is the right order to use in science class or what happens if they deviate from this order. Overall, it seems to the student to be a tortuous method just to arrive at an answer the teacher knew all along. It leads students to deny their own experiences and observations in favor of the expected outcome of a demonstration lab. In other words, students quickly learn certain words (those of scientists) are better than others (their own), as are certain inferences, arguments, and explanations.

Alternatively, when students experience school science intended to capture a learner perspective, their everyday methods and processes are expanded, transformed, and deliberately chosen for study. Learners act within the context of what it means to generate credible information (create tools for thinking) and to use and test information for decision-making and explanation construction. By studying their own processes of tool production and their use of these tools in learning actions or problem solving (e.g., knowledge-acts) we can immediately position students as researchers of methods and processes for transforming phenomena into explanations. The term knowledge-acts initially sounds cumbersome. We are trying to capture the sense that knowledge is not a static truth but rather an activity continuously being produced through human action. By thinking about acts of knowledge instead of facts of knowledge, the human activity is constantly made visible. As students compare their methods to those of others in their community and then to those of
career scientists, they can begin to see how and why observations and descriptions in science tend to be mathematized (e.g., to facilitate communication and collaboration) as well as how and why explanation in science comes in a variety of forms (e.g., because they arise from using various methods). Students come to view the variety of methods and processes used in science as fluid and dynamic guidelines they can use to answer questions and test assumptions as they try to make sense of the natural world. This view is consistent with the everyday practices students initially bring to school science, but students taught considering a learner perspective through practice, research, and comparison learn to critique, revise, and improve their own methods and are empowered to coordinate and conduct their own investigations alone or in collaboration. Table 1.3 summarizes this alignment of the presentation of method from the two perspectives.

Table 1.3. Methods and processes of knowing as viewed from disciplinary and learner perspectives

<table>
<thead>
<tr>
<th>Disciplinary perspective</th>
<th>Learner perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everyday phenomena are transformed into the unfamiliar</td>
<td>Everyday phenomena are expanded and theorized</td>
</tr>
<tr>
<td>Oriented toward finding right answers through demonstration labs</td>
<td>Oriented toward finding credible answers through various means</td>
</tr>
<tr>
<td>There is a correct method to use to solve a particular type of problem</td>
<td>Methods are guidelines for planning and interpretation—there are often several ways to arrive at the same conclusion</td>
</tr>
<tr>
<td>There is a single scientific method</td>
<td>There are many types of methods and these are fluid and dynamic, never repeated the same way twice by the same person or between people</td>
</tr>
<tr>
<td>We do not study our methods, we study the world with our methods</td>
<td>Our methods are open for study, critique, and change</td>
</tr>
</tbody>
</table>

Nature of scientific knowledge. When norms, assumptions, and rules for what we mean when we say we know something or what we consider to be knowledge and knowing are taught from a disciplinary perspective, children are likely to see them as just another set of rules to remember. In fact, they are not far off. One philosopher of science, Larry Loudan wrote on this topic that, “It is probably fair to say that there is no demarcation line between science and non-science, or between science and pseudo-science” (Loudan, 1983, p. 112). Science educators, however, continue to claim there are significant differences between everyday knowledge and knowing and science knowledge and knowing. For example, Norm Lederman and his colleagues (e.g., Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) developed seven statements about the nature of scientific knowledge quite popular among science teacher educators for teachers and their students to learn (summarized in Table 1.4, left column).
Table 1.4. Characteristics of scientific knowledge commonly referred to as the nature of scientific knowledge

<table>
<thead>
<tr>
<th>Discipline perspective</th>
<th>Learner perspective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific knowledge is never absolute or certain; it is subject to change</td>
<td>How do we decide we are confident in a claim–evidence conjecture?</td>
</tr>
<tr>
<td></td>
<td>How do we decide to question a claim–evidence conjecture and explore it further?</td>
</tr>
<tr>
<td>Scientific knowledge is empirically based; observations are distinct from inferences</td>
<td>What is the evidence a concept exists in reality?</td>
</tr>
<tr>
<td></td>
<td>What is the evidence that the concept may not exist in reality, but be a useful conceptual tool until we have a better idea of what reality is?</td>
</tr>
<tr>
<td>The myth of the scientific method; there is no single method that will guarantee infallible knowledge is created</td>
<td>(See Table 1.3)</td>
</tr>
<tr>
<td>Scientific knowledge is, at least partially, based on and/or derived from human imagination and creativity; functional models of natural objects (e.g., atoms, species, genes) are not copies of reality</td>
<td>Why is creativity important?</td>
</tr>
<tr>
<td></td>
<td>How do scientists foster creativity?</td>
</tr>
<tr>
<td></td>
<td>What types of creativity have I used when I am working on a scientific problem?</td>
</tr>
<tr>
<td>Scientific knowledge necessarily is partially subjective and can never be totally objective because scientists hold particular beliefs, prior knowledge, training and experience, which all influence their work</td>
<td>How are facts, laws, concepts, ideas, laws, and theories generated in science?</td>
</tr>
<tr>
<td></td>
<td>How do my beliefs and prior knowledge influence what I look for and what I find when I conduct an explanation and try to create an explanation?</td>
</tr>
<tr>
<td>The relationship and distinction between scientific laws and theories. Scientific theories are not guesses, they are inferred explanations for observed phenomena; theories do not become laws once they have been proven; laws are descriptive statements usually expressed mathematically</td>
<td>What is theorizing?</td>
</tr>
<tr>
<td></td>
<td>How do we describe patterns we see in nature?</td>
</tr>
<tr>
<td></td>
<td>How do we know a law can be universally applied (i.e., is “true” throughout the universe)?</td>
</tr>
<tr>
<td>Science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded</td>
<td>Who decides what is worth studying?</td>
</tr>
<tr>
<td></td>
<td>What science does the public (the government) fund?</td>
</tr>
<tr>
<td></td>
<td>Who decides what phenomena in the natural environment we are allowed to study?</td>
</tr>
<tr>
<td></td>
<td>How does one get to be on a review panel that decides which proposal receive financial support?</td>
</tr>
</tbody>
</table>
First, students should learn scientific knowledge is based on empirical evidence—evidence we have directly or indirectly gathered through our five senses (sight, taste, touch, smell, and hearing). Knowledge cannot be based on the existence or work of a supernatural entity (gods, spirits, ghosts, etc.) or the result of superstitious ritual. This statement about empiricism also means scientific knowledge must be intended to reflect reality or be accountable to reality. There is nothing wrong with this statement; it just does not convey its deep meaning to new learners. Questions they might find more interesting are whether particular conceptualizations of reality they are studying (e.g., food webs, gravitational fields, kinetic energy, igneous rock) actually exist in the physical world (i.e., an entity exists that the concept faithfully replicates) or whether the concept is (purely) a useful representation or approximation and may not have a tangible or specific equivalent. Also, learners might enjoy asking, “How was this concept (or idea, theory, law) we are studying first developed? Was it based on empirical observations or was it inferred from some experience or both?”

Current presentations of the nature of science teach students theories and laws are not equivalent kinds of knowledge and theories do not become laws when they are proven. It is not actually clear why this is so important to know. Like many terms in science also used in everyday conversation, word meanings change depending on the context. This is true in the case of laws and theories. In everyday conversation, laws are typically absolute and cannot be broken without consequences. Theories, on the other hand, are viewed as guesses. In science, these terms have alternative meanings. Theories represent well-articulated explanatory models or frameworks for understanding a phenomenon universally, and they are based (usually) on a large collection of experiments and other types of investigation. Laws are mathematical descriptions of natural phenomena that appear with regularity under particular conditions.

Although helping learners build their science vocabulary is important for improving their ability to communicate, it may be more useful if learners are asked to consider and study ideas that underlie these terms, ideas such as universality, regularity, and conditionality and how these characteristics of knowledge are determined. For example, how do we know a theory or law is universally true or that phenomena can be considered regular and, therefore, predictable? The same critique can be used against all seven statements science students are told to learn about the nature of scientific knowledge: Why have students memorize blindly this arbitrary set of statements when simple inquiries can reveal their ambiguity and lack of universality?

In Table 1.4, we propose some examples of simple inquiries from a learner perspective that could lead to fruitful investigations into the nature of science. We agree with Loudan (1983), these inquiries should not be used to demonstrate how science knowledge is different from other knowledge. Rather, science knowledge
undergoes more scrutiny and critique than knowledge-acts for other purposes. We are not proposing all of these inquiries be pursued in one episode, but over the course of 6 to 7 years of science education (K–6) an elementary school teacher team may discover student interest in these inquiries. Students might be interested in the history of experimentation and why it is so popular among scientists. Students might want to know how to identify a model in science or learn how to create a model themselves and test its utility. Students might like to explore socioscientific issues such as how policymakers and the public make decisions about how people should be allowed to live, adapt, and transform their world using information generated by scientists (e.g., making decisions about curbing climate change, understanding the various ways to conduct risk–benefit analyses, whether new weaponry should be developed). Students might like to explore the mathematization process to understand how phenomena can and cannot be described mathematically and how they distinguish between these conditions.

Michael Matthews is a science educator who specializes in how the history and philosophy of science is, and can be, incorporated into school science teaching and learning. He suggests the characteristics of nature of scientific knowledge listed on Table 1.4 should be renamed “Features of Scientific Knowledge,” and he proposes a variety of topics science students (K–12 and beyond) might research over the years of their schooling. These include technology, worldviews and religion, theory choice and rationality, realism and constructivism, feminism, and explanation (Matthews, 2012).

To conduct this comparative analysis of the disciplinary and learner perspectives shown on Tables 1.2, 1.3, and 1.4, we used a process the feminist sociologist Dorothy Smith (1987) calls “keeping the everyday world problematic.” As we mentioned earlier, the discipline perspective, embedded in the three-legged stool model of science and science education, was ubiquitous when we first started our work together, and it persists today. This means the stool model represents everyday educational practice or at least what the science education community wants this everyday practice to be. Whenever we are faced with the everyday world treated as a single universal idea unrelated to a particular standpoint, we follow Smith’s lead and ask, “Is this portrayal partial, limited, located in a particular standpoint and/or permeated by special interests and concerns?” (adapted from Smith, 1987, p. 20). Indeed, when we finally examined the three-legged stool with these questions in mind, we found the model reflected the standpoint of disciplinary experts (career scientists and science educators). It is permeated by the special concerns and interests of this group to create a science education that supports the development and expansion of the professional scientific enterprise through public support as well as new recruits in the science career pipeline. Each leg is actually a partial and limited view of the discipline and one that promotes scientific work as complex and difficult, best left to authorities and experts who will share answers with us as they are generated. After using an analysis of everyday practice inspired by Smith, we positioned ourselves as learners (based on our work with children) and began
constructing an alternative world from a perspective that might resonate with their interests and understandings and make our jobs as teachers a little bit easier in terms of helping students take charge of their learning.

SCIENCE AS A SYSTEM OF HUMAN ACTIVITY

Our framework for science education is based on the idea science is a system of human activity. Science is not synonymous with nature or the world. When pro-science advocates and enthusiastic educators exclaim, “Science is everywhere!” we warn you to remember this phrase is shorthand for the opinion “The opportunity to look at the world scientifically is everywhere” or “The products of scientific investigations of the world are everywhere.” As teacher educators we often hear many of our students interpret the phrase to mean the natural world itself is science. That is, animals are science, phase changes (ice, to water, to steam) are science, metamorphic rocks are science, glaciers are science, and so on. These objects are not science because science is a human invention. We recommend a book by Catherine Milne (2011), one of the editors of this series, for a compelling introduction to the history of science as a human invention. In other words, science is a human activity.

By activity, we are not referring to everyday activities like brushing our teeth, baking cookies, playing Frisbee, or commuting to school; these are all goal-directed actions. We are using the term as it is typically used in cultural historical activity theory: a system of human actions, interactions, and transactions whereby a subject (a person, team, or machine) works on an object (e.g., material object or problem-space) in order to obtain a desired outcome. In order to do this, the subject employs tools, which may be external (e.g., books, computers, equipment) or internal (e.g., concepts, plans, algorithms) (e.g., Kozulin, Gindis, Ageyev, & Miller, 2007). Examples of human activities include science, medicine, law, education, labor and services, and each has three central aspects: production, distribution, and exchange or communication.

In science, the primary practice is on understanding and explaining phenomena in the natural world; therefore, the activity involves producing information and explanations, distributing them, and exchanging or communicating ideas to facilitate further production. In another example, the primary practice of medicine is to understand how to cure or treat people with diseases, and the overarching activity involves producing the tools and practices for health and wellness, distributing these products, and exchanging and communicating these to facilitate further progress. The primary practice of education is on coordinating the processes of teaching, learning, and human development through curricula and transactional experiences. Broadly, the practice of education involves producing or forming the learning activity, where learners become aware of the goals and motives of education and develop an interest in and an initiative for learning, analyzing, and solving problems and drawing their own conclusions. According to Harmut Giest and Joachim Lompscher (Giest & Lompscher, 2003):
Learning activity is a special kind of human activity … [and it] cannot be reduced to the acquisition (or “construction”) of domain-specific knowledge. It is a process of acquiring the domain-specific activity itself in all its complexity as a product of cultural-historical development—according to the level of the learners’ … zones of actual performance [and] proximal development. A major task for the teacher, therefore, consists of creating conditions under which the learning activity makes sense for the students and may be formed according to the learning object (e.g., science), or organizing the students’ learning activity as interaction and cooperation, of giving the necessary learning means or leading the process of finding and further developing them … the teacher has to guide learners in such a way that they experience learning as a meaningful, necessary activity that makes them increasingly competent and independent. (p. 270)

In other words, the learner must be included in generating the purpose and meaning of the problem solving they do in school, whether it is learning words can have multiple meanings, the Earth’s position and tilt relative to the sun can explain the seasons, or sound is a type of pressure wave. They need opportunities to question what they are learning (and why) as part of the process of growing their interest, curiosity, and initiative. In the practice of education, the distribution and exchange aspects of the activity refer to the institutions we create for education, where tools for thinking are passed from person to person and from generation to generation.

Using this model of human activity we can think of science as a systematic whole with a complex meditational structure evolved over several hundred years and should be thought of as a dynamic system (Figure 1.3) of human interactions.

One way to categorize and study these interactions in our classrooms is based on the major elements found in the human interactions that take place in any activity: subjects, objects, outcomes, tools, rules and schema, community, and division of labor.

The subject is the individual or groups of individuals involved in the activity (e.g., students and teachers). The object is also the motive of the activity—the problem-space or material the subject works on. The tools include any resource the subject uses on the object of the activity (e.g., concepts, equipment, books, ideas). The rules and schema are any formal or informal regulations that can affect how the activity takes place. The community is the social group the subject belongs to while engaged in an activity. The division of labor refers to how the tasks are shared among the community. The outcome of an activity system is the result of transforming the object of the activity (Yamagata-Lynch, 2010). Initially, this model of human activity feels a bit cumbersome, but once we start using it to view various activities around us it starts to make sense and we can see how it might be useful to examine our own classrooms using this systematic approach to investigating teaching and learning. Let’s look at a traditional notion of the practice of science through this lens.
In science, the main subject is the career scientist. From the perspective of this scientist what are some of the rules, norms, or conventions that typically constrain his or her work? When career scientists want to share a claim about how some aspect of the world works with others, they are expected to provide evidence in support of their claim. That’s a pretty solid rule. They are also not allowed to appeal to supernatural entities in their explanations, nor are they allowed to fabricate evidence. These are two other solid rules. Of course, scientists have broken each of these rules, but when they do, they are often no longer considered scientists and may eventually be ostracized from their community. Otherwise, they can invent and defend any method of investigation they want and explore any aspect of the natural world that interests them. In other words, when we look closely, there are not too many rules for the practice of science in general.

The tools of a scientist include physical tools such as scientific equipment used to take measurements or make observations as well as conceptual tools such as explanations, concepts, norms, and skills (i.e., all of the information available in books, journal articles, or presented at meetings).

The community of a scientist can be conceptualized on at least three levels: local, regional and global. Their local community includes other scientists interested in the
same problem or phenomenon (e.g., the vision of Mexican cave fish). These people could be in the same research group, classroom, or connected through the peer review process during dissemination and communication. A larger community might include anyone working on the biology of the Mexican cave fish or the ecology or ecosystems of the fish. Their global community would include all scientists working in any problem-space.

How are labor, power, and status in the practice of science divided among members? Science today (and in the past) is typically organized, like many other occupations, as an apprenticeship model. Whether we are referring to formal science training, crowdsourcing citizen science, or the learning of an individual enthusiast, a more experienced and productive subject (referred to as an expert in an apprenticeship model) tends to hold more power and status than a less experienced subject (referred to as the apprentice in this model). Expert subjects tend to do less of the physical work (e.g., conducting investigations and experiments) and more of the intellectual work (e.g., planning investigations; building hypotheses, models, and conclusions) as well as the broader dissemination and communication work (e.g., writing and reviewing papers, applying for and reviewing grants, and speaking at conferences). Apprentice subjects, on the other hand, do more of the physical labor with their intellectual effort typically guided by, or done in collaboration with, an expert.

Our portrayal of science using the triangle model shown in Figure 1.3 is only one of many possible portrayals of a traditional view of the activity of science. Does your view of science match ours, or is it different? How do we differ, and what does this mean to you? If your interpretation differs significantly from ours, do you think you still can understand our perspective? If not, what would you ask of us to help clarify our position?

Even though the activity system diagrams we have drawn appear fixed and static, its developers insist we interpret it as a three-dimensional, moving, and dynamic image—ever changing by the constant actions of the subjects and all their interactions within the system. For instance, as a subject works on an object or problem-space it may be transformed into an outcome, which then becomes a tool or rule. There is constant construction and renegotiation within the activity system. For example, as each object is transformed and a new or modified object replaces it, tasks might be reassigned and reconceptualized, rules might need to be reinterpreted or bent, new tools may be needed, and new communities may be necessary. Furthermore, given the dynamic nature of any system based on interactions, these interactions can be sites of contradictions and tensions that can create pressures within the system, which can encourage or inhibit development or become the reason for changing the nature of an activity.

In our BBST Framework (Figure 1.2), we propose science education should be centered on a learner perspective and the project of being becoming scientists. In other words, learners should view themselves as both subjects and objects of the system. Not only are they oriented toward transforming a particular problem-space or material object; they are also oriented toward transforming themselves as they
learn how to conduct the transformation of the object or problem into an outcome. It is challenging to explicitly capture the power of each aspect of the activity system in science education. We propose two possibilities to convey how science and science education can be portrayed.

First, science education and science can be viewed as interconnecting but separate systems (Figure 1.4a). One system represents a traditional view of science from the perspective of the career scientist as the primary subject and the natural world as the object (Figure 1.4a lower right). This science system is connected at two major nodes to the system of science education (outcome–subject and outcome–tools). The latter system represents a traditional view of science education from the perspective of the teacher as subject and student as object. In this model of science education activity (Figure 1.4a center left), teachers are responsible for transforming each new class of students—over the course of a school year (or workshop, or summer, or other curriculum schedule)—into people who know more scientific facts, information, and methods than they knew at the beginning of the school year (or other schedule).

The primary tools of the teacher are various instructional materials (e.g., lesson plans, demonstration labs, teacher manuals, curriculum guidelines), standards for learning, formative and summative assessments, science-related equipment and supplies, and digital and print resources. Although teachers are cognizant of the rules and schema used in science, school and classroom rules of conduct and performance are at the forefront of most interactions. The teacher’s community varies, but consists of her fellow teachers and other school personnel as well as

Figure 1.4a. Science and science education viewed as interconnected human activities
any professional developers or scientist partners with whom they work. In other words, careful attention must be paid to a learner perspective when a teacher plans what learning opportunities to provide for his or her students and how the students will engage with them; otherwise science education is typically conducted from the perspective of the teacher or other experts within the discipline. Design from a learner perspective foregrounds learner-relevant questions whereas design from a disciplinary perspective foregrounds expert knowledge—what is known already and what was learned by someone else in response to the problem they faced. An important consequence of the separation of the two viewpoints is teaching about science is necessarily distinct from the actual practice of science.

In an alternative portrayal of how science and science education can be represented, we consider science education and science from the perspective of a learner–scientist instead of a teacher or career scientist. From this standpoint, science education and science can be seen as an inseparable whole, with the subjects in the system all oriented toward transforming a problem-space that always includes the subjects themselves (Figure 1.4b).

![Figure 1.4b. Science and science education viewed as inseparable human activities](image)

In this model, learner–scientists (i.e., anyone interested in science such as school students and career scientists) are responsible for not only transforming a particular natural phenomenon into an explanation, but also for transforming themselves as they come to understand the natural phenomenon. The primary tools of the learner–scientist are the various instructional materials provided by a teacher, expert, mentor or other resource; a resource who acts as a mediator filtering the meaning and
creating the norms for knowledge building (e.g., teacher, expert); formative and summative assessments; science-related equipment and supplies; and various digital and print resources. The learner–scientist’s community includes others interested in the same phenomenon (e.g., a learner’s classmates, other learner–scientists they meet through citizen science projects, or teams of scientists), and the rules and schema reflect the institutional rules of science as well as those of their local learning context. When teachers plan learning opportunities for students from the learner–scientist perspective modeled here it brings their role as mediators to the forefront and reminds us to position students as active learners (subjects) rather than as objects. In other words, learning is something we help students do, not something we do to them.

Now, when we take the model in Figure 1.4b and superimpose the questions from the BBST framework listed on Table 1.1 as shown in Figure 1.5, we can see more clearly how a learner perspective can influence not only curriculum decisions and instructional materials design, but also the types of questions we expect and encourage learners to ask as they establish themselves as learner–scientists.

![Figure 1.5. Questions a learner–scientist might ask about the science activity system](image)

The types of questions we model and propose learners ask were designed to (1) help the activity of the system remain focused on the human actors and (2) help students see themselves as subjects. This makes it more likely learner–scientists will see people like themselves and people they know ultimately create the activity we call science, not some unrelated, anonymous, famous, or inaccessible group of unusually smart and intelligent people working tirelessly to make discoveries under strict rules of knowledge production.
CHAPTER 1

CONCLUSION

The framework for BSST is our approach to science education. It positions students as researchers of their world, including what it means to be and become a scientist. The current three-legged stool approach to science education is difficult to implement in practice because it separates knowledge, methods, and theorizing into separate domains, which in practice cannot be separated. This approach also describes “what is”, according to scientists and science educators, and it constrains our views of learners as people who need to learn canonical facts, practices, and ways of thinking. The BBST framework, on the other hand, helps all learner–scientists ask, “what could be” and positions them, immediately and consistently, as researchers of “what is” and developers of “what could be.” In the BBST framework there is no separation between knowledge, methods, and theorizing in science. Instead, these are central topics for investigation whenever canonical material is presented. A common mantra in elementary education is to help students make connections between what is being taught and what they experience in their everyday lives. What better way to make this connection than to adopt a learner perspective and expand the questions students already puzzle about?
CHAPTER 2

BEING AND BECOMING SCIENTISTS

What Does It Mean to Be|Become a Scientist? Who Can Be|Become a Scientist? How Do I Be|Become a Scientist? How Am I a Scientist Today?

In science a beginner will certainly read or be told “The scientist this” or “the scientist that.” Let him not believe it. There is no such person as the scientist. There are scientists, to be sure, and they are a collection as various in temperament as physicians, lawyers, clergymen, attorneys, or swimming-pool attendants. Scientists are people of very dissimilar temperaments doing different things in very different ways. Among scientists are collectors, classifiers, and compulsive tidiers-up; many are detectives by temperament and many are explorers; some are artists and others artisans. There are poet-scientists and philosopher-scientists and even a few mystics (and even a few crooks). What sort of mind or temperament can all these people be supposed to have in common? Obligative scientists must be very rare and most people who are in fact scientists could easily have been something else instead.

— Medawar, 1979, p. 3, emphases in original

IT’S ALWAYS TIME TO CHALLENGE AND RECONSTRUCT IDEALS

Imagine you are a child of 4 or 5 years and have never met a scientist. The only images of scientists you’ve seen are from popular media outlets such as cartoons, movies, advertisements, comic books, and TV. These images are almost always of either great scientists like Albert Einstein, Isaac Newton, Galileo Galilei, Charles Darwin, and Marie Curie, or fictional characters that wear lab coats and goggles, and work with brightly colored, dangerous, bubbling chemicals in a laboratory. These images are almost always white men or boys. If you are having trouble believing this assertion, just type scientist in the Google Image search engine and you’ll get the picture. Now, imagine you go to school and learn scientists are supposed to work hard, work for the common good, be open and not secretive, be objective, be logical, and be skeptical of ideas that lack empirical evidence. You might also learn they are supposed to observe the world carefully, describe what they see in exquisite detail, and do fair tests and experiments. Through these actions, they are somehow able to explain how the world works to other people who have not done these things. To a child, these scientist-people might start to seem powerful, genius, or even a little strange.
CHAPTER 2

With such clear and detailed descriptions and qualifications of what it means to be a scientist, and what scientists must do, permeating popular culture and school science, perhaps it is not surprising some of our students see themselves as scientists while others do not. Perhaps it is not surprising some teachers with whom we work treat some students as scientists, but do not treat others as scientists. Perhaps it is not surprising some students of our teacher candidates may even like science based on these images and experiences, but still have no desire to be a scientist. What is surprising is regardless of the efforts made by hundreds of science educators, teachers, scientists, and students to reconstruct these images and views—they still persist! Don’t believe the hype. Stop and challenge stereotypical images of scientists. We show how teacher, parents and students can reject idealized images and we present an alternative conceptualization of being and becoming a scientist.

As the introductory quote from Peter Medawar (a Nobel prize–winning biologist) implies, not only is it futile to try to describe the temperament or qualities of a scientist, there is also no reason to do it. An obligative or ideal scientist is a fiction. Would we spend much time listing the temperament or character traits of an ideal teacher, lawyer, nurse, carpenter, shopkeeper, or electrician and believe only people with those traits can be teachers, lawyers, nurses, carpenters, shopkeepers, or electricians? Many of us have and do, but this is wasted time for sure. Do we think if we teach a particular set of character traits then the person will be successful at a particular occupation (or worse, do we believe someone born with a particular temperament will be successful)? Many of us do believe this, but it is time to look at people’s lives and contributions and question this belief. Consider an eighth-grade calculus teacher who worked highway construction during the summer to supplement his income and put his children through college. Is he a teacher or a construction worker? How about the research ecologist who performs in a local chamber music group—is she an ecologist or a musician? The answer is they are both, and they are each successful at both, for reasons similar to and different from all other teacher-construction workers or ecologist-musicians. Furthermore, what makes one a good musician may not have anything to do with what makes her a good ecologist. What they all (teacher, scientist, lawyer, nurse, shopkeeper, electrician, carpenter, ecologist-scientist, teacher-construction worker) have in common, however, is they engaged in some goal-oriented, object–motive activity in which they grew increasingly competent and earned some sort of capital (social, cultural, and symbolic), which in turn granted them entry into these fields of practice, profession, and study. For the rest of the chapter, we consider what it means to be and become a scientist and who can do it. The short answer is anyone can be and become a scientist.

Being and Becoming, Learning and Knowing, Transforming and Changing

What does it mean to be someone? What does it mean to become someone? We say these phrases all the time: I am a teacher. I am a second grader. I want to become a doctor. She wants to be a police officer. We want to be rich. He wants to be
successful. You want to be a person who fights racism. I want to be a person who fights sexism. But what do these phrases mean? How do we become someone? How do we know when we are someone? We argue being and becoming are inseparable. In other words, we are always simultaneously being and becoming who we are and want to be (Figure 2.1).

![Figure 2.1. Being and becoming are interdependent, simultaneous processes; we are always being and always becoming](image)

One of our colleagues, a developmental psychologist, Anna Stetsenko (Stetsenko, 2008) defines becoming (and being) as the process by which individuals come to understand and transform the world and themselves by contributing to the world. This means there is no gap between changing or transforming one’s world, learning and knowing one’s world, and being or becoming oneself (Figure 2.2).

![Figure 2.2. Self-development can be thought of as a collaborative transformative practice, which refers to the endless, interconnected, and dynamic processes of being and becoming, knowing and learning, and transforming and changing oneself and one’s environment (adapted from Stetsenko and Arievitch, 2004)](image)

Unfortunately, most science educators usually think of this single process (being|becoming) as five distinct processes (learning, knowing, becoming, being, and contributing), which we conduct in distinct moments in time with clear gaps between them.
CHAPTER 2

Think about how we (in the United States) often present the process of becoming a scientist to students. First, students are told if they want to be a scientist (in the future) then they should learn a lot of information, work hard to be promoted, and perform well in plenty of math courses to ensure entry into a college that supports science majors. Second, future scientists should major in a science discipline in college. If possible, they should get experience on a research project with a team of scientists in their field of interest. Third, to become an accredited scientist, students should go to graduate school and earn a master’s or doctorate degree in their area of interest. Fourth, after completing school and earning a degree in some area of science, graduates should start working independently as a career scientist and publish papers, which can be considered original contributions to the field. If we represent this timeline graphically we might draw a progression like the one in Figure 2.3.

![Figure 2.3. Being and becoming a scientist is typically presented as a linear process punctuated by some type of postsecondary or graduate certification](image)

There are many ways to represent the processes of becoming a scientist and being a scientist. The points here are (1) these two processes are often thought of as connected linearly in time (being a scientist refers to a future time in a student’s life, while becoming refers to the present actions the students need to take); (2) it is not clear how being and becoming are somehow related to the separate processes of knowing and learning; and (3) the outcome of the process is usually a career scientist. First, there is apprenticeship, a discrete period of nonbeing (e.g., “not a scientist yet” or “only a student”). Second, there is accreditation, which usually dictates when the apprentice has earned the ability to make original contributions. People who violate this sequence are labeled as genius, child prodigy, gifted, or unusual in some way. This sequence is a human construction designed for exclusion and exclusivity. Once we recognize this status quo, we can reconstruct it to resemble a more productive and inclusive reality. We’re not advocating for abolishing professional licensure requirements (they certainly revolutionized how we protect the public from charlatans), only for recognizing how these requirements might unnecessarily limit and dismiss.

In Stetsenko’s model, changing one’s world, knowing one’s world, and being/becoming oneself are all part of a single continuous process. A linear progression (like the one in Figure 2.3) is artificial because it is not possible to separate the lifelong process of human development into discrete stages or periods.
of knowing, being, and transformation. She and Eduardo Vianna (Vianna and Stetsenko, 2011) explained it this way:

People not only constantly transform and create their environment, they also create and constantly transform their lives and themselves … there is no gap between changing one’s world, knowing it, and being (or becoming) oneself …. All three dimensions emerg[e] and develop synergistically within and through collaborative transformative practice. (pp. 317–318)

Let’s explore their model further by examining some everyday examples of being/becoming.

**Being/becoming a bird watcher.** When students learn a bird’s call or song, they will say they now hear it everywhere. They became attuned to a phenomenon always present, but previously below their conscious awareness. One of our first responses to learning something new is to teach it to someone else. We might now say, “Oh, did you hear that? It sounded like a cardinal!” Another response is to learn more: “Do cardinals have more than one song or call?” “When does the bird make that call?” “What does the call mean to other birds?” “Do birds hear what I hear or do they hear something different?” “How might we answer these questions?” “How does it sound do us? Can we describe its rhythm, tone, pitch, or repetition?” “How does it make us feel? Is it pleasant, annoying, easy to ignore, captivating, or painful?” We transformed our environment the moment we distinguished the bird call from other sounds, for this changed us and our consciousness and we are part of the environment interacting with this bird. Another moment of transformation was when we learned from another person (a teacher, friend, guide, book, recording) the name of the bird that makes that particular call because this changes what we look for (a perching bird with red, brownish-red plumage over its entire body, red beak, black face and neck mask) and how we see or “read” the world. We are now someone who can identify a cardinal by call and by sight; we can teach others; we can use this tool to make observations and conduct investigations; we can seek out others who are interested in learning more; we can reflect on our interactions with this creature and learn more about ourselves and our interactions. If we took action and did one or more of these things, a teacher or researcher might say we were doing science or talking scientifically.

**Being/becoming a person who keeps a science journal.** When we, or our students, keep science journals we record impressions of the world—what we see and what we think—in the form of drawings, pictures, photos, diagrams, notes, narratives, tables, and charts. As we create the journal pages we are/become people who keep journals. Both the habit of keeping a journal and the physical journal entries structure how we view the present, revisit the past, and change how we manage our time and activity in the future. In other words, as we learn or know the world,
we transform the world and how we look at it, which in turn has the potential to change what we want to do, who we are, or who we want to be. For example, in a unit on food webs, we asked our students to assess their initial claims or hypotheses about the relationships between various living organisms through a review of the evidence they had gathered. Subsequently, they generated even more sophisticated and investigable questions about food webs than they had generated without this reflection.

When we document our learning and knowing of the world in a science journal we transform the world into our own language and make the world familiar and predictable. Through reflecting on our documentation process, however, we can identify the lenses we use to view and interpret the world and the inherent limitations. We challenge ourselves to invent alternatives, explore other perspectives, and ask new questions. When children keep science journals (of their own creation) and begin to rely on them, they can become more conscious of past actions, the power of reflection, and become oriented toward future goals.

Being|becoming aware of environmental consequences of personal actions. By choosing to drive our cars into the city instead of taking public transportation, we initiate numerous changes in the environment, which in turn change us because we are part of the environment. For example, we produce far more greenhouse gases when we take the car, which in turn contribute to climate change, which will eventually dictate our future responses to the environment (where we live, what we eat, what we wear). We usually read when we ride on the subway or bus. When we drive, however, we often rant. In other words, our choices affect our mood and physical health. When we drive we add to the vehicular load of the city—we displace residents from their parking spaces, we add particulate matter to the air, increasing the smog, which in turn contributes to the higher asthma rates of our students. As we learn more about the ramifications of our choices, it changes how we view the world. If we change our decisions based on what we have learned and know about the world we are/become people who have made our decision making conscious and reflective.

Being|becoming ecologists. In elementary school ecology lessons, when we build food webs with children and look at the effects such as changing the amount of food (prey), number of predators, types of prey/food, types of predators, and number or amount of decomposers, we learn about perspective and system connections. From whose perspective is there an apparent benefit from the change? From whose perspective is there a risk or loss from the change? Structuring and investigating the world in this way has the potential to change how a student sees individuals—viewing them now as part of a larger, interdependent, connected system. Identifying systems and our place within a particular system can shift our mind-set from viewing ourselves as individual humans to viewing ourselves as members of a larger
collective of interconnected living and nonliving things. In other words, we can shift how our actions and choices indirectly and directly affect others in profound and potentially unanticipated ways.

* * *

What do each of these examples of being|becoming have in common? In addition to illustrating the irreducible interconnections between being, knowing, and transformation, they also illustrate examples of being and becoming scientists. The moment we wonder about our actions or other phenomena and begin to question, compare, document, or measure these actions and phenomena or conduct experiments and investigations to explore and explain them is a moment when we are being|becoming scientists.

Through these examples, we attempted to illustrate Stetsenko’s claim there is no gap between changing one’s world, knowing it, and becoming oneself. Instead, we should view these as three dimensions of an expansive collection of collaborative transformative practices necessary for human development. All human activities (including education) represent contributions to collaborative transformative practices: “These practices are those in which people come to know themselves and their world as well as ultimately come to be human in and through the processes of collaboratively transforming the world in view of their goals” (Stetsenko, 2008, p. 472). These practices are contingent on the past and the vision for the future and are imbued with ideology, ethics, and values. For example, when we notice and discriminate a birdcall for the first time we might attempt to see the source and create a description, which gives us access to a proper name (invented by a predecessor), which gives us further access to all we think we collectively know about this bird. These tools we use are part of our collective past (tools generated by others in an effort to understand this bird) and can be marshaled for our future goals (e.g., to learn more about this and other birdcalls or to learn to discriminate a variety of calls from this bird). How this knowledge further transforms our interactions reflects our values, ethics, and commitments. For example, in the process of learning about this bird’s song we may learn this bird prefers to nest in dense thickets, so we might think twice about clearing that patch of yard that is a bit of an eyesore to us, but looks attractive to the bird. Alternatively, we might encourage others in our community to consider how to create this type of habitat in areas favored by the birds. Ultimately, noticing and learning about a local bird constitutes a contribution achieved through collaborative transformative practice: knowing, becoming, and transforming our world and ourselves. This practice can be applied to any problem space in the natural world, such as our understanding of the impact of humans on the environment (e.g., how we consume and conserve water, air, and carbon resources), our understanding of the origins of the universe and life, our understanding of human systems of governance and economics, or any other area of interest. In Box 2.1, we’ve provided an example of an organizer you
can use to apply the collaborative transformation practice to any area of interest. This will help you to stop thinking of becoming and being as discrete processes and to reimagine the process of being/becoming a scientist as the endless, simultaneous, interconnected, and dynamic process of being and becoming, learning and knowing, and transforming ourselves and our world.

**Box 2.1.**

*Applying the BBST framework for collaborative transformation practice*

**Instructions:** Pick something in the natural world you enjoy learning about. Use the table below, based on Figure 2.2 to map as many events, ideas or scenarios related to the topic onto the three aspects of collaborative transformation practice.

**Topic:** Rock cycle – Erosion  
**Activity:** Observing local schoolyard embankment erosion

<table>
<thead>
<tr>
<th>Being</th>
<th>becoming</th>
<th>Knowing</th>
<th>learning</th>
<th>Changing</th>
<th>transforming</th>
</tr>
</thead>
</table>
| • Interested in monitoring local erosion  
• Aware of cost and damage  
• Curious about effects of erosion on sewer system functioning | • Water flowing or trickling across loose soil will move fine particles farther across the sidewalk than larger particles (pebbles, rocks)  
• When a higher volume of water flows down the embankment (as in a heavy rainstorm), more soil washes onto the sidewalk and into the street. Smaller particles are still carried further than larger particles, but everything travels further | • Consulted with school maintenance supervisor about causes and possible repairs.  
• Maintenance department is considering a combination of netting and bushes as a possible solution to the embankment erosion. |
Now we want to expand on this idea and argue teaching and learning science constitutes a contribution to these broader practices as a whole. All of these examples illustrated being/becoming a scientist, and these are the reference models we promote in our classrooms. But these are not the images typically presented to science students in any grade, kindergarten through graduate school. Where did the traditional notions of scientists as professional experts come from, and what images are popular among schoolchildren?

WHO CAN BECOME A SCIENTIST? MYTH AND REALITY

History and Origins of the Word Scientist

In 1962 Sydney Ross, a professor of chemistry and science historian, wrote an essay for the Annals of Science that shed some light on the origins of our concept of scientist (Ross, 1962). In it, he explained William Whewell invented the word scientist relatively recently in his 1834 anonymous review of one of Mary Somerville’s books (On the Connexion of the Physical Sciences). Somerville was a polymath, science advocate and one of several female science writers working the in the 1830s. These prominent women wrote reviews and syntheses of research, which were undoubtedly sources of new ideas for budding and working natural philosophers of the day. For example, Michael Faraday was an avid reader of Jane Marcet’s books and was inspired to study the natural world as a result. Marie-Anne Pierrette Paulze (a.k.a. Madam Lavoisier) was instrumental in interpreting and translating Lavoisier’s work so it could be understood by his contemporaries. And Somerville’s writing influenced James Maxwell’s work and led John Adams to look for Neptune. A year after Connexion was published, Somerville was one of the first women elected to the Royal Astronomical Society in 1835 along with Caroline Herschel. In Connexion, Somerville had brought together in one textbook the latest developments in the fields of astronomy, physics, chemistry, botany, and geology. She explained “The progress of modern science, especially within the last five years, has been remarkable for a tendency to simplify the laws of nature, and to unite detached branches by general principles” (Somerville, 1834, preface). Around the time Somerville was writing, members of the British Association for the Advancement of Science were starting to complain that philosopher was too broad a term to be used to describe themselves and they had no word to describe a person who pursued science. Whewell introduced the word scientist in his review of Somerville’s recent book by analogy with artist, economist, atheist, and sciolist (someone who talks with pretended expertise). Apparently, he was joking (as indicated by sciolist), but despite its unofficial introduction, the word quickly spread and it was added to the Oxford English Dictionary as a new word in the same year of its introduction (Oxford English Dictionary [OED], 2014b). In 1840 Whewell proposed it again (this time seriously) as a new and necessary word to describe “a cultivator of science in general” (Ross, 1962). In the years after it was introduced,
however, Whewell’s new word faced harsh criticism from prominent British citizens such as Michael Faraday (a British bookbinder and self-taught chemist and physicist), who refused to use the word and continued to refer to himself as an “experimental philosopher”; Lord William Kelvin (a Scottish mathematician and physicist), who instead attempted to promote the use of naturalist to reflect the work of “a person well versed in natural philosophy” (1890); Sir John Lubbock (a British banker, philanthropist and polymath), who suggested we retain the old word philosopher (1894); and a popular writer of the time, Grant Allen (a Canadian science writer and science fiction novelist), who suggested most publishers preferred to use man of science over scientist—as was the case between 1894 and the early 20th century (ca. 1914) (Ross, 1962).

Objections were raised to the use of the term scientist for many reasons, but not perhaps for the reasons we might hope. According to Ross (1962), for some, the word implied the practice of science could be used to earn a living. At the time, educational reforms had already begun to place the learned professions (e.g., physician, clergyman, and lawyer) on par with technical professions (e.g., factory worker, mechanic). It was argued adding scientist to the list of career options would lessen the stature of all those labeled scientists. For others, the word was a Latin-Greek hybrid and, therefore, not a legitimate word. In other words, the Brits objected to the authenticity of the term. Another related and popular objection was the mistaken belief Americans had adopted it; their approval automatically implied it must be an unseemly word. In fact, an American had not invented the word. It wasn’t until 1849 that an American was credited with using the word. American astronomer Benjamin A. Gould proposed it and Ross explains Gould was unaware he was not the first to do so (Ross, 1962, p. 73).

No one, however, objected to the notion scientist was a word invented to be an “exclusive title held by a small group of professional men” (Ross, 1962, p. 75). Nor did anyone object to the implication that the knowledge of this group of men would be superior to all others whose knowledge would be “deemed no better than nescience [lack of knowledge or awareness] or ignorance” (Ross, 1962, p. 75). By the early 20th century, the name was viewed as an honorific title soon to be sought after by many. Quickly, scientists were viewed as the only producers of true belief about the world and how it works (i.e., truth or true knowledge), and educational institutions were regulating who could be a scientist and how they became one. In other words, knowledge about the world generated by all other scholars (and, it goes without saying, laypersons) including philosophers, writers, artists, historians, and theologians, was considered faulty, untrustworthy, wrong or pointless. The belief among some that science could answer all of life’s questions would prove to be a persistent worry for many. One of the major concerns with the invention and expansion of the modern scientist in Britain was whether the new professional scientists would “promote safe religious belief or a dangerous secular materialism” (Holmes, 2008, p. 450) in their attempts to answer all of life’s questions including those about origins, existence, divinity, and the afterlife.
Regulating Being and Becoming a Scientist

The creation of the professional title of scientist meant now any student (well, European males) could aspire to be career scientists and universities could provide the coursework and certification (e.g., a college degree) to achieve it. Generally, once an official route to acquire a professional title is created regulation eventually follows and, in the case of science, such regulation can affect not only the possibilities of being and becoming scientists, but also:

- The number of workers.
- The demographics of the workers.
- The access and entry routes for workers.
- The income of workers.
- The public perception of science and scientists.
- The division of labor within a particular field of science.

Since the bulk of professional research in the United States is currently supported almost entirely by grants from the National Institutes of Health, the National Science Foundation, the Institute of Educational Sciences of the Department of Education, the Department of Energy, and the Department of Defense and these grants are only available to applicants who are employed at colleges, universities or research institutes, or (in some cases) businesses. It is within this system that access and entry pathways are constructed.

Access and entry. Through regulation, the educational process of being/becoming a scientist was separated into discrete events. Becoming was viewed as training on the road to an endpoint of being an economically active scientist (i.e., earning a living wage through science) (Figure 2.3). This linear and compartmentalized path has existed for about a century and a half (it is only now starting to change a bit), and has been recently dubbed the science career pipeline. We could not trace the origins of the pipeline analogy, but it refers to the narrow scientific career track we use in the United States for scientific training, from elementary school to initial employment. Students pass through a series of transition points such as completing coursework and apprenticeships at various levels before reaching the final level when they are certified as scientists and can contribute to the field through independent work and publication. The pipeline analogy refers to positive aspects of the certification system (steady flow and assured delivery of career scientists), but it also refers to negative aspects of the same system. As Henry Etzkowitz, Carol Kemelgor, and Brian Uzzi (2003) explain, “A pipeline also connotes a narrow, constricted vessel with few if any alternative ways of passage through the channel” (p. 6). If for some reason you are ejected or rejected from the pipeline it is difficult to regain access, because at each educational level the entries become fewer and more restrictive. In other words, the linear path of becoming and being a scientist supports the belief scientist should be an “exclusive title held by a small group of professional men” (Ross, 1962).
Public perception of scientists. With regulation, a mythology began to emerge about the disposition, temperament, and personality required for being a scientist (e.g., Medawar, 1979). Whewell himself defined a scientist as “a cultivator of science in general,” but the Oxford English Dictionary added a scientist was “A person who conducts scientific research or investigation; an expert in or student of science, esp. one or more of the natural or physical sciences” (OED, 2014b). The term evolved over time and eventually it referred to a person with distinct mental attitudes (e.g., skepticism of authority, dispassionate description of phenomena) who uses techniques developed by practitioners of physical science (e.g., framing hypotheses capable of being tested, measuring the limits of reliability of data). For example Robert Merton, a sociologist studying science, outlined four sets of values and norms to which men of science subscribed: universalism, communalism, disinterestedness (or no conflict of interest), and organized skepticism (Merton, 1973, pp. 268–278). Character traits such as curiosity, persistence, open-mindedness, serendipity, integrity, and intelligence are often suggested as common to any positive scientific attitude. According to Ross, by the 1960s a dangerous view of a scientist as an omniscient authority was popularized as a “new figure of authority, corresponding to the priest or witch doctor of a more primitive culture, whose scientific statements can be accepted with child-like reliance” (Ross, 1962, p. 83).

Around the same time, government agencies investing in science education were interested in the public perceptions of science. Margaret Mead and Rhoda Métraux (1957) were commissioned by the American Association for the Advancement of Science (AAAS) to find out what high school students thought about scientists, including what kind of scientist students would like to be (or not to be) if they chose to become scientists themselves. At the time, the AAAS had invested in creating positive attitudes to the idea of science (e.g., funding the Traveling High School Science Library Program). The assumption operating in this and similar programs was if students learned positive attitudes to science in general (by learning about real scientists), then they would consider careers in science. Mead and Métraux investigated this assumption. They distributed the following prompts to 35,000 students at 145 high schools, many of which were participating in an AAAS-sponsored library program:

If you are a boy, complete the following statements in your own words:

1. When I think about a scientist, I think of …
2. If I were going to be a scientist, I should like to be the kind of scientist who …
3. If I were going to be a scientist, I would not like to be the kind of scientist who …

If you are a girl, complete the following statements in your own words:

1. When I think about a scientist, I think of …
2. If I were going to be a scientist, I should like to be the kind of scientist who …
   OR If I were going to marry a scientist, I should like to marry the kind of scientist who …
3. If I were going to be a scientist, I would not like to be the kind of scientist who … OR If I were going to marry a scientist, I would not like to marry the kind of scientist who …

We hope you noted the way the questions were altered for participating girls, and we’ll return to the issue of sexism in science and science education in the section on regulating demographics.

After the authors selected and analyzed a subset of the responses, they found the official image of the scientist given by participants (i.e., what students probably felt was the correct answer) was a very positive image.

Science in general is represented as a good thing: without science we would still be living in caves; science is responsible for progress, is necessary for the defense of the country, is responsible for preserving more lives and for improving the health and comfort of the population. (Mead & Métraux, 1957, p. 384)

However, when participants were asked about the kind of scientist they would choose to be (or not to be), their image of a career as a scientist was overwhelmingly negative. We wonder whether heroic biographies like those available through the Traveling High School Library Program may have exacerbated the problem, but this hypothesis was not investigated as far as we can tell. On Table 2.1, we created a graphic model of the authors’ original composite images of the positive and negative sides of being a scientist as expressed by student-participants.

The kind of scientist the students wanted to be (i.e., their positive image) still reflected a bleak picture of life as a scientist. Even though the positive image sounded noble and good, it wasn’t very appealing. For example, students reported if they were a scientist they would want to be one who was a genius or almost a genius, serious, selfless, hard working, self-sacrificing, responsible, and invested a lot of time and money in becoming a scientist. The authors argued these positive qualities were not qualities most students were interested in developing. Participants did not wish to “commit themselves to longtime perspective, to dedication, to single absorbing purposes, to an abnormal relationship to money, or to the risks of great responsibility; and these requirements “[were] seen as far too exacting” (Mead and Métraux, 1957, p. 387). Mead and Métraux argued the positive and negative images both represented extremes—“too much contact with money or too little … confined work indoors, or traveling far away; talking all the time in a boring way, or never talking at all”—and all were “deviations from the accepted way of life, from being a normal friendly human being, who lives like other people and gets along with other people” (Mead and Métraux, 1957, p. 388). Furthermore, any career seen as antithetical to that contemporary set of values would “repel male students” from choosing it as a career and repel females students from supporting it as a career choice for their husbands. For these reasons, the authors argued students could hold stereotypical, albeit positive, images of scientists in general, but also have no interest
Table 2.1. Comparison of student responses about personal preferences provided the Mead and Métraux report

<table>
<thead>
<tr>
<th>Positive image</th>
<th>Negative image</th>
</tr>
</thead>
<tbody>
<tr>
<td>If I were going to be/marry a scientist I should like to be/marry the kind of scientist who …</td>
<td>If I were going to be/marry a scientist I would NOT like to be/marry the kind of scientist who …</td>
</tr>
<tr>
<td>He is a very intelligent man—a genius or almost a genius.</td>
<td>He is a brain; his is so involved in his work that he doesn’t know what is going on in the world. He has no other interests and neglects his body for his mind. He can only talk, eat, breathe, and sleep science.</td>
</tr>
<tr>
<td>He spent long years of expensive training during which he studied hard.</td>
<td>His is always reading a book. He brings work home and also bugs and creepy things.</td>
</tr>
<tr>
<td>He is interested in his work and takes it seriously.</td>
<td>He neglects his family—pays not attention to his wife, never plays with his children. He has no social life, not other intellectual interest, no hobbies or relaxations</td>
</tr>
<tr>
<td>He is careful, patient, devoted, courageous, open minded.</td>
<td>His work is uninteresting, dull, monotonous, tedious, time consuming.</td>
</tr>
<tr>
<td>He knows his subject.</td>
<td>He bores his wife, his children and their friends—for he has no friends of his own or knows only other scientists—with incessant talk that no one can understand; or else he pays not attention or has secrets he cannot share.</td>
</tr>
<tr>
<td>He records his experiments carefully; he does not jump to conclusions; he stands up for his ideas even when attacked.</td>
<td>(no parallel statement)</td>
</tr>
<tr>
<td>He works long hours in the laboratory, sometimes day and night, going without food and sleep.</td>
<td>He spends his days indoors, sitting in a laboratory, pouring things from one test tube into another.</td>
</tr>
<tr>
<td>He is prepared to work for years without getting results and face the possibility of failure without discouragement; he will try again. He wants to know the answer. One day he may straighten up and shout: “I’ve found it! I’ve found it!”</td>
<td>Though he works for years, he may see no results or may fail.</td>
</tr>
</tbody>
</table>
### Table 2.1. (Continued)

<table>
<thead>
<tr>
<th>Positive image</th>
<th>Negative image</th>
</tr>
</thead>
<tbody>
<tr>
<td>He is a dedicated man who works not for money or fame or self-glory, but for the benefit of mankind and the welfare of his country (like Madam Curie, Einstein, Oppenheimer, Salk).</td>
<td>He is likely to receive neither adequate recompense nor recognition. He may live in a cold-water flat; his laboratory may be dingy. If he loses touch with people, he may lose the public’s confidence—as did Oppenheimer. If he works for money or self-glory he may take credit for the work of others—as some tried to do to Salk. He may even sell secrets to the enemy.</td>
</tr>
<tr>
<td>Through his work people will be healthier and live longer; they will have new and better products to make life easier and pleasanter at home, and our country will be protected from enemies abroad.</td>
<td>If he works by himself, he is alone and has heavy expenses. If he works for a big company, he has to do as he is told, and his discoveries must be turned over to the company and may not be used; he is just a cog in a machine. If he works for the government, he has to keep dangerous secrets; he is endangered by what he does and by constant surveillance and by continual investigations.</td>
</tr>
<tr>
<td>He will soon make possible travel to outer space.</td>
<td>(no parallel statement)</td>
</tr>
<tr>
<td>He is truly a wonderful man. Where would we be without him?</td>
<td>A scientist should not marry. No one wants to be such a scientist or to marry him.</td>
</tr>
<tr>
<td>The future rests on his shoulders.</td>
<td>(no parallel statement)</td>
</tr>
</tbody>
</table>

in being or marrying scientists personally. In other words, being a scientist is a fine career choice for someone else—someone uniquely qualified for the work or born to be a scientist.

Apparently, not much has changed (in Britain, at least). In a longitudinal study being conducted at the time of this writing, Louise Archer, Jennifer Dewitt, Jonathan Osborne, Justin Dillon, Beatrice Willis, and Billy Wong (2010) have been tracking the attitudes of students toward science and scientists over the course of five years, from age 10 to 14. This research group is tracking 9,000 students in four schools in the London area and recording their attitudes toward science, scientists, and their school science classes, their out-of-school interests and leisure pursuits, their aspirations for the future, and the influences on their future aspirations. In the first year of the study, fifth-grade students (age 10–11) overwhelmingly reported they enjoyed
school science (they find it fun and interesting), but they did not see themselves as scientists (it’s not for them). The reasons they cited for this opinion are not as detailed as those from the Mead and Métraux study of U.S. high schoolers, but they were similar to those of the students participating in the 1950s study. Namely, their positive images of being scientists were still unappealing. For example, although the participants felt “one not need be naturally clever to be good at science … they felt interest, appreciation, effort, and concentration” (Archer et al., 2010, p. 629) were important. Furthermore, they explained scientists have to “keep an open mind” and “learn about all different topics,” not just one of interest. The participants felt that to be good at science you have to have a “natural interest” in all subjects of science and this interest is necessary for paying attention, remembering facts, and doing well in class (p. 630). Students with a “natural interest” were referred to as “science people” who have a “science mind,” or occasionally with the more derisive term, “boffin,” meaning egghead or nerd in the U.S. Many participants described scientists as geniuses and often eccentric—people they had little interest in becoming.

Many researchers have asked young students about their views of scientists and what they do (i.e., doing science) and have claimed students hold stereotypical views of who can be a scientist and what kind of work they do (e.g., conducting experiments; handling dangerous chemicals). They have also claimed that participating students rarely portray themselves as scientists. Most reports explain children have either what researchers called “traditional views” of a normal scientist working in a laboratory (usually a white male with a lab coat and glasses or goggles surrounded by equipment) or “mythical views” of mad scientists (such as a Jekyll/Hyde or Frankenstein-like character who works in a dungeon and does strange experiments):

- David Chambers asked 4,807 children ages 5 to 11 years old to “draw a scientist” on a piece of paper; 96.5% of the drawings were of traditional stereotypes, and only 3.5% of the drawings were of mythical stereotypes (Chambers, 1983).
- Renato Schibeci and Irene Sorensen asked elementary school children in grades 1–7 from one school in rural Western Australia (“consisted of black children,” N = 463) and in grades 1–5 from one school in urban Perth, Western Australia (“attended predominantly by white children,” N = 4,762), to “draw a scientist.” Both groups of children drew stereotypical images, but the participating white students tended to average more stereotypical indicators (e.g., equipment, hairstyle, location, clothing) at each grade level than did the participating black children (Schibeci and Sorensen, 1983).
- Kevin Finson asked 190 eighth-grade students of various ethnicities (white, Native American, and African American) to “draw a scientist” on a piece of paper. The majority of participating students made stereotypical images. Finson reported no significant differences between drawings of students from various racial groups participating in the study (Finson, 2002).
- Mehmet Buldu asked 30 Turkish children ages 5–8 to “draw a scientist doing science and explain your drawing”. Sixty-five percent drew stereotypical
scientists (e.g., biologists, chemists, lab technicians, computer scientists, doctors, astronauts); 35% drew social scientist types (e.g., journalists, novelists/poets, artists, university professors as teachers). More than 50% of the students drawing stereotypical scientists, however, did not include the traditional indicators identified by other researchers (e.g., lab coats, goggles, chemicals) (Buldu, 2006).

Even as data accumulated supporting the position that the majority of students held stereotypical views of scientists regardless of socioeconomic status, ethnicity, or gender, several researchers were modifying their data collection tools (i.e., their interview questions, prompts, and tasks) and finding children may hold more complex views than previously thought including multiple definitions of the word scientist:

- Mícheál Maoldomhnaigh and Áine Hunt asked 76 fifth-grade children to “draw a scientist.” After the participants completed their first drawing, the authors asked them to draw another scientist. The frequency and appearance of mythic stereotypes changed from one set of drawings to another (more mythical drawings were found to occur in second drawings than first). No male participants drew a female scientist in either drawing; 31% of the drawings done by female participants showed a female scientist, and more girls drew a female scientist in their second drawing than in their first (Maoldomhnaigh and Hunt, 1988).

- Mícheál Maoldomhnaigh and Vera Ní Mhaoláin divided 367 students into roughly two equal groups and asked one group to “draw a scientist” (DAS) and asked the other group to “draw a man or woman scientist” (DAMWS). The found changing the wording of the directions altered the types of drawings produced by participants. Under the DAS instruction, females drew female scientists 28% of the time in their first drawing and 66% of the time in their second drawing. Under the DAMWS instruction, however, females drew female scientists 49% of the time in their first drawing and 61% of the time in their second drawing. Of the drawings received by males in either condition, however, only one female scientist was drawn (from the DAS group) (Maoldomhnaigh and Mhaoláin, 1990).

- Donna Farland-Smith and William McComas asked elementary school students to “imagine that tomorrow you are going on a trip (anywhere) to visit a scientist in a place where the scientists is working right now. Draw the scientist busy with the work this scientist does. Add a caption that tells what this scientist might be saying to you about the work you are watching the scientist do.” Student-participants made their drawing on one third of a piece of legal-size paper folded into three equal portions. When they were finished drawing one scientist, students were instructed to unfold the paper and draw two more scientists on the same side of the paper as the first, using the directions previously described. Students were not told in advance they would be making multiple drawings (this was called the E-DAST, Enhanced Draw-a-Scientist-Test). Seventy-six percent of the time, a student’s first drawing is not their only perception of a scientist (Farland-Smith and McComas, 2009).
As demonstrated in these studies, the wording of a task or an interview question can influence the participant’s response. It’s not unreasonable to wonder whether there is a point in continuing this line of research. We think researchers continue investigating students’ images of scientists because they believe they have shown a link between students’ perceptions of scientists and attitudes toward science as well as a link to their selection of a career. Therefore, the recommendation is science educators should attempt to report and determine which attitudes influence whether students pursue science in higher education and how to foster positive attitudes that lead to science career aspirations (e.g., Farland-Smith, 2012). Another belief these researchers share is their view of being and becoming scientists. All the studies reviewed so far view the process as discrete steps (Figure 2.3), with becoming separated in time from being and students positioned as outsiders to science. The prompts in all of these studies asked about career scientists in general, not about students as scientists. We argue that this stems from the tradition of certification and that, through this work, scientists interested in education and science education researchers continue to consciously or unconsciously promote the elitism and exclusion that still accompanies regulation. As long as researchers continue to position children, students, and nonscientists as outsiders, then their findings should evoke scrutiny and their proposed solutions or interventions to improve students’ solutions may be ineffective at best or backfire at worst.

Some researchers have begun to ask students how they see themselves as scientists and this approach is beginning to stimulate new questions:

- Charles Barman recruited 154 teachers in 23 states and asked them to learn about their students’ views of science and scientists. These teachers asked 1,504 students to draw themselves as scientists and followed up with interviews. In a one-on-one DAST with an interview teachers asked students: (1) will you please draw a picture of a scientist doing science? When you are finished, will you please explain your drawing? (2) On another piece of paper, will you please draw a picture of yourself doing science in school? When you are finished, will you please explain your drawing? (3) Can you think of some ways you use what you learn in science outside of school? (Colored pencils and crayons were provided for all drawing tasks.) The majority (84.5%) of K-5 students interviewed depicted themselves as active learners, while the remainder (15.5%) viewed themselves as passive learners (seated at a desk reading a book or taking notes). Most students in grades 3–5 (84%) reported they think they can use science outside of school and felt they could generalize the use of skills and knowledge learned in science to everyday situations (52%). Younger students (K–2) also reported they could use science outside of school (59%), but many also could not see a use for science outside of school (41%) (Barman, 1999).

- Junqing Zhai, Jennifer Jocz and Aik-Ling Tan interviewed 161 fourth-grade students from two high-performing schools in Singapore. They asked the participants to (1) draw and label themselves doing science in class and (2) draw
and label a scientists doing science in real life. They found students’ images of scientists are shaped by their school experiences and vice versa. For example, 60% of participants drew themselves engaged in activity (a “hands-on” activity), but only 25% reported the activity was motivated by a purpose or a research question. Ninety percent of participants drew scientists engaged in hands-on work, but only 39% reported a purpose or research question. Only 16.5% of students illustrated themselves working in groups, and only 2.5% showed discussion. Even though collaborative work and discussion dominate career science, students only indicated scientists engaged in any group work in 8% of the drawings. About one fifth of the students (21%) depicted themselves listening to the teacher or watching demonstrations. No students drew scientists learning from a teacher despite the extensive mentoring provided in the common apprenticeship model of certification. Finally, students drew themselves and scientists completing workbooks (15% and 3%, respectively) (Zhai, Jocz, & Tan, 2013).

Although Barman, Zhai, and colleagues asked student-participants to show how they see themselves as scientists, they also asked them to compare their images to images of “scientists doing science in real life” (Zhai et al., 2013). In other words, even through they elicited images of students as scientists they still maintained a divide between students and career scientists. The students they interviewed divided into two groups as well. One group interpreted “doing science” as creating knowledge (what career scientists do). The other group interpreted learning about science as understanding preexisting knowledge (what students and nonscientists do).

We did find one group of researchers who elicited children’s images of scientists without any explicit comparison career scientists. In their work with elementary school children, Maria Varelas, Justine Kane, and Caitlin Wylie (2011) talked with children (grades 1–3) about their experiences in science and what they had written in their science notebooks. Their questions focused on the children as scientists rather than on their impressions of scientists in general. For example, rather than asking students to draw a scientist at work and describe what the scientist was doing, they asked: What kind of science student do you think you are? What makes you think of that? How does this journal page show that you are a scientist? Are you like a scientist? How would you describe yourself as a scientist? (Varelas et al., 2011, p. 831). The findings from their interviews informed our own practice. Notably, they did not attempt to generalize to all students, but instead documented how the children’s views of themselves in relation to science and school vary. Some students blended their conceptions of participating in school with their conceptions of participating in science, while others kept them separate. Some students saw scientists had unique features, while others saw scientists had the general qualities of “good people” in functional societies like school. Some saw science as a body of knowledge (information); some saw caring for animals, people, and earth as important in science; some brought up the actual capital they associated with scientists; and others referred to their own social and cultural capital as they engaged
in science; and others did neither (Varelas et al., 2011). We can take from this report at least two conclusions. First, students hold a variety of views on the topic of what it means to be a scientist. Second, their views may be influenced more by school behavioral norms than by stereotypical images of scientists they encounter in the media.

Varelas and her colleagues considered the second conclusion in some detail and argued children’s views about scientists and themselves as scientists probably reflected the content of the conversations they have had with their teachers and peers over time. For example, students whose interactions with teachers were dominated by conversations about classroom management may tend to relate and conflate (1) the norms of scientific practice (which the authors refer to as doing science) and (2) the rules of school (referred to as doing school). The authors found this relationship in their discourse analysis when some participants explained that during science students (and scientists) should: raise their hands, be focused, work hard, help others, respect the teacher, do what they are told, stay in their seats, spell correctly, learn a lot of information, do well on tests, work hard to be promoted; and students and scientists should not: talk too much or misbehave. In other words, doing science reflected the rules of school. On the other hand, students whose interactions with teachers were dominated by conversations about science-related topics and investigations may tend to relate doing science to whatever norms the teacher has developed for science rather than for classroom management purposes. Varelas and her colleagues also found this relationship because other student-participants viewed scientists (and students) as people who “build, design, share, test out, observe, write, draw, try to get it right, figure things out, experiment, explore, discover, think about what they do and why, take care of living and nonliving things, find clues, measure, get ideas from books, and have fun” (Varelas et al., 2011, p. 845).

Based on the work by Varelas and her colleagues, we might argue we need to pay as much attention to how our school practices and classroom norms depict career scientists as we pay to how these same practices and norms influence children’s depictions of themselves as scientists. These science education researchers noted many children in their study fused good behavior with being scientists, and they noted these students were mostly girls. The observation children mentioned “behavioral norms as dimensions of doing science may mean they have constructed the view that unless they behaved well they would not have access to science, and would be invisible, outsiders, and left out” (Varelas et al., 2011, p. 846).

What can we do to prevent students from receiving mixed messages about being/becoming scientists? The most common advice for helping students develop realistic views and images of scientists cited in the science education research literature includes: (1) inviting guest speaker scientists to talk with teachers and students about their work (especially females and people of color); (2) teaming with industrial or university partners to engage in meaningful and purposeful research
and/or engineering projects; (3) take virtual and/or actual field trips to see scientists at work; (4) interviewing scientists; (5) reading scientists’ biographies; (6) targeted career exploration; and (7) discussing stereotypes presented in the media (e.g., Finson, 2002; Mason, Kahle, & Gardner, 1991; McDuffie, 2001; Quita, 2003).

Although participating in activities like these are essential to science teaching and learning, and we have had some success with these approaches, there are two major concerns. First, all these activities still focus on professional or career scientists and may result in a limited view of being|becoming scientists if not framed from a learner–scientist perspective. Second, only when students are positioned as researchers of what it means to be|become a scientist can we ensure they are not conflating norms of school behavior with norms of science behavior. In other words, only when we listen to students as we guide them will we understand how they view the process of collaborative transformation. With our help, students can find answers to questions about the status quo as well as identify possible alternatives. Ultimately, the research questions will reflect the types of inquiry students and teachers feel they need to conduct with the intention of keeping the everyday world of practice in science problematic. Some possible questions include:

- How would I find out how a scientist behaves or what a scientist does?
- Why can’t a scientist be this or that?
- How do I think a scientist behaves? Why? Are there other alternatives?
- How many definitions of a scientist can we come up with?
- What work have I done to demonstrate I am (or am not) a scientist today? Why?
- When my teacher says “Scientists are good listeners, so I should be a good listener, too,” what does she mean and how does she know all scientists are good listeners?
- When my teacher says, “Scientists stay in their seats,” what does he mean and how does he know all scientists stay in their seats?
- How do I think a person becomes a scientist? Why? Are there other alternatives?
- Maybe it makes more sense to refer to specific types of scientists (e.g., ecologists, geologists, molecular biologists) than to use scientist as a generic label. How does this affect how I think about scientists?

When students couple these types of investigations with interviews with scientists, projects with scientists, and reflection on their own work as scientists, they might be more likely to develop robust personal images of themselves as scientists and more realistic images of scientists in general.

Not only do we need to help students to question the status quo they encounter, we teachers also need to question the norms we create. In our own work, we have recently become very interested in how to adjust our talk with students so our mediation practices are in keeping with the vision we proposed in Figure 2.2. One of the approaches we are exploring is how to encourage students to pursue their interests when expressed to us. For example, if a student says, “I want to be a meteorologist when I grow up,” we avoid entering a conversation that adopts a mythical future endpoint (be a meteorologist); instead, we promote the real and present process of
being/becoming. The following transcript of a conversation between Sue and Bella reflects this commitment. We have been developing a range of possible alternative endings (see Alternatives A–C) that could be explored in future conversations with Bella or others as they arise.

Transcript 2.1. Example of a conversation promoting the practices of being and becoming a scientist today

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bella</td>
<td>I want to be a meteorologist when I grow up.</td>
</tr>
<tr>
<td>Sue</td>
<td>Why do you have to wait until you grow up? Can you do it now?</td>
</tr>
<tr>
<td>Bella</td>
<td>[Shrugs.]</td>
</tr>
<tr>
<td>Sue</td>
<td>What do you think a meteorologist does?</td>
</tr>
<tr>
<td>Bella</td>
<td>They are on TV and they tell you the weather.</td>
</tr>
<tr>
<td>Sue</td>
<td>Okay. Can you tell me the weather today? Or the weather right now?</td>
</tr>
<tr>
<td>Bella</td>
<td>[Giggles.] It’s cloudy with some sun.</td>
</tr>
<tr>
<td>Sue</td>
<td>Good! That’s very good. It is cloudy with some sun. You can tell me the weather right now. What else does a meteorologist do?</td>
</tr>
<tr>
<td>Bella</td>
<td>[Shrugs.]</td>
</tr>
<tr>
<td>Sue</td>
<td>Does she tell us what the weather will be tomorrow?</td>
</tr>
<tr>
<td>Bella</td>
<td>[Nods.]</td>
</tr>
<tr>
<td>Sue</td>
<td>Yes, she can predict what the weather will be tomorrow, and that’s really useful, right? She can help us plan, like, think about what kind of clothes and shoes to wear, right?</td>
</tr>
<tr>
<td>Bella</td>
<td>Yeah, like, today, I didn’t have to bring my umbrella to school.</td>
</tr>
<tr>
<td>Sue</td>
<td>Me neither! So, can you predict what the weather will be tomorrow?</td>
</tr>
<tr>
<td>Bella</td>
<td>[Eyes widen.] No.</td>
</tr>
<tr>
<td>Sue</td>
<td>Well, that’s something you can start to learn more about tonight, right? It seems you can do some of the things a meteorologist does, but you know that there are some things you cannot do yet, so there are still more things you want to learn.</td>
</tr>
<tr>
<td>Bella</td>
<td>Yeah.</td>
</tr>
<tr>
<td>Sue</td>
<td>Do you think the meteorologist on TV is done learning?</td>
</tr>
<tr>
<td>Bella</td>
<td>[Shrugs.] No?</td>
</tr>
<tr>
<td>Sue</td>
<td>You sound like you are not sure—maybe you think there is a right answer, but you don’t know what it is. How about this question: If you start being a meteorologist today, when do you think you’ll be done learning everything there is to know about the weather and how it works?</td>
</tr>
<tr>
<td>Bella</td>
<td>(See alternative exchanges A, B, and C below.)</td>
</tr>
</tbody>
</table>
It is not the most riveting conversation, but it was an early conversation illustrating how we have started to explore new approaches to talking about being|becoming scientists consistent with Figure 2.2. In this exchange, we focused on what Bella imagined a meteorologist knows or does. After that we began to outline what she could and could not already do and what her next steps for learning more might be. As a means to create and practice new habits of talking, we discussed various alternative responses and how the conversation might be continued. Here are some of the options we think are consistent with the vision in Figure 2.2. What alternatives can you imagine?

**Alternative exchange A**

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Possible transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bella</td>
<td>Maybe after I finish college?</td>
</tr>
<tr>
<td>Sue</td>
<td>In that case, let me ask you this: Pretend we both just finished college and we are meteorologists. Do you think it’s possible that we could know everything that a meteorologist who has been working for 20 years as a TV meteorologist knows about the weather and how it works? [Possible follow-up: I think it depends on a lot of things. What you think it depends on?]</td>
</tr>
</tbody>
</table>

**Alternative exchange B**

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Possible transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bella</td>
<td>I don’t know. I don’t think I’ll ever be done learning because there’s always more to learn.</td>
</tr>
<tr>
<td>Sue</td>
<td>I agree with you. I wonder, why do you think there is always more for all of us to learn? I think there are a lot of possible answers to that question.</td>
</tr>
</tbody>
</table>

**Alternative exchange C**

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bella</td>
<td>Maybe when I’m on TV!</td>
</tr>
<tr>
<td>Sue</td>
<td>So, when you get an official job as a TV meteorologist, that’s when you’ll be done learning about the weather and how it works? What if part of the job is to report on hurricanes and someone invents a new way to track hurricanes and comes up with a new explanation for why they travel the way they do? Do you still think you and other meteorologists will be done learning then?</td>
</tr>
</tbody>
</table>

The point is to practice responding to students like Bella by reconstructing assumptions about being, knowing, and transforming, and how we conceptualize collaborative transformation around the problem-space of being|becoming scientists. This does not need to be limited to students’ views of scientists’ tools for thinking or
their knowledge-actions. For example, with older students, we might also ask what kind of life they want to live and whether being a meteorologist could be consistent with their aspirations. In these conversations, we want to be alert to stereotypes that may prevent students from pursuing further study such as the belief scientists have no job security, scientists make very little money, scientists have no time for family or friends, or science is a man’s field (or a white man’s field). This brings us to how demographics are regulated in science.

Regulating Demographics. Scientist as an Exclusive Title Held by a Small Group of Professional Men: Images of Women as Scientists

Archer and colleagues’ (2010), in their ongoing study tracking a cohort of students in Britain over time from fifth to tenth grade, have found that, by fifth grade, boys and girls already view science as masculine, that is, as a career more appropriate for men. This is not a new finding, nor does it seem to have changed much over time. In Mead and Métraux’s 1957 publication, it appears none of the young female participants in the study imagined themselves as career scientists, but we cannot be sure. Mead and Métraux did not review all 35,000 essays in their report, nor did they comment on whether any female respondents wrote about themselves as scientists or only wrote about marrying a scientist.

Regardless of how researchers frame the question about scientists, the majority of boys in all the studies reviewed here represent scientists in their drawings as men or boys. Even in studies where boys were asked to draw multiple pictures of scientists, they usually drew males in all their pictures. Although boys consistently drew males (their own image), girls consistently ignored their own image (female) and drew scientists as men or boys. Even with specific encouragement, only 25–66% of girls drew female scientists in the various studies. One can conclude girls are less likely than boys to view themselves as scientists, starting at an early age.

- David Chambers observed only girls drew women and girls as scientists and only 28 women scientists were drawn by girls, who made up 49% of the participants (Chambers, 1983).
- Micheál Maoldomhnaigh and Áine Hunt observed when participants were asked to make two drawings no male participants drew a female scientist in either drawing. Only a third (31%) of the drawings done by female participants depicted female scientists. More girls drew a female scientist in their second drawing than in their first suggesting they may think the male in their first drawing is the more acceptable image (Maoldomhnaigh & Hunt, 1988).
- As we noted previously, Micheál Maoldomhnaigh and Vera Ni Mhaoláin observed under the DAS instruction, 28% of participating girls drew women scientists in their first drawing, but 66% drew women scientists their second drawing. Under the DAMWS instruction, 49% of female participants drew women in their first drawing and 61% drew women in their second drawing. Of the drawings received
by males in either condition, however, only one female scientist was drawn (this participant was a male from the DAS group) (Maoldomhnaigh and Mhaoláin, 1990).

- Charles Barman observed students in grades K–2 drew females in their drawings more often (42%) than students in grades 3–5 (27%) or grades 6–8 (25%) (Barman, 1999).
- Donna Farland-Smith observed when using the E-DAST, 56% of American female participants drew female scientists, 38% of Chinese female participants drew female scientists, 14% of American males drew female scientists, and 6% of participating Chinese males drew female scientists (Farland-Smith, 2009).

There are many hypotheses for why girls feel excluded from science (and may have difficulty visualizing themselves as scientists), and all of them relate to gender schemas and gender socialization. According to the Report of 2012 National Survey of Science and Mathematics Education, 94% of elementary school teachers are female; it is likely one out of every two teachers have at some point in their lives been told or believed “science is not for girls” (Banilower et al., 2013). This is a sobering statistic, and it means most of us have confronted or still need to confront and change this belief and prevent its perpetuation.

Girls and boys are socialized from birth to act a certain way, look a certain way, and are encouraged to fit into their respective gender roles in all aspects of life, including the selection of their career (if they even have that life option). Various assumptions have historically pervaded gender schemas and female socialization in the United States and often go unchallenged today. In our work with teacher candidates we typically must challenge and reconstruct the following assumptions:

**Assumption 1.** Women and girls (as well as men of color) are “less than.” They are viewed as less strong, less intelligent, less emotionally stable, less rational, less resilient, or less competent.

**Assumption 2.** Women and girls are more suitable for pink-collar jobs in the helping or service professions, which typically pay lower wages and are less desirable for men, who are responsible for financially supporting their families.

**Assumption 3.** Women are expected to assume family-related responsibilities, including meeting the needs of all familial children, husbands, parents, grandparents, and relatives.

**Assumption 4.** Women should not compete with men for jobs with higher wages or positions of power or leadership.

**Assumption 5.** Women and girls who want to pursue positions of leadership or display stereotypical masculine characteristics (e.g., assertiveness, competitiveness,
independence, courage, or career focus) should be or can be justifiably ostracized, discouraged, or harassed by their families, supervisors, mentors, and/or other community members.

These views of women and girls persist around the world today to varying degrees and are used to deny women and girls an education and/or career experience (e.g., OECD Development Center, 2015). We argue that all of these assumptions underwrite the belief math and science are for boys. Discrimination against women and girls in science ranges from the subtle (not acknowledging women and girls for their contributions and ideas) to the blatant (denying their access, participation and contribution by refusing them an education). In the United States, the idea girls do not do well in science and math are based on the analysis they are often—inadvertently—treated differently in the classroom because they, their teachers, and/or their families hold one or more of the assumptions listed above. Since only 30% of elementary school teachers report feeling prepared to encourage their female students’ participation in science and/or engineering it may be a relief to know there are a variety of resources to learn more about gender inequality and how to promote gender equity in our classrooms (Banilower et al., 2013). We believe by shifting the way we talk about becoming scientists, we will be able to make it clear to all students they can chose to become scientists today and we as their teachers will provide a safe and productive place for those collaborative transformation practices.

When approaching a gender equity research or reflection project, we advise teacher-colleagues to begin by using instructional resources such as case studies or vignettes to stimulate self-reflection and reveal their assumptions about what they think boys and girls can do. One resource we have found very helpful in our work is the handbook by Liesl Chatman, Katherine Nielsen, Erin Strauss, and Kimberly Tanner (Girls in Science: A Framework for Action; Chatman, Nielsen, Strauss, & Tanner, 2008). The vignettes, written by teachers and scientists, illustrate strategies for reaching a variety of gender equity goals in science classroom teaching and learning and are a great introduction to common issues teachers face. Once readers have identified the assumptions they hold about girls (and boys) in science, we suggest they document the extent to which these assumptions influence their teaching transactions with children.

The easiest way to start this process is to record your practice for a week. Analyze the resulting video or audio with a colleague or trusted friend who is engaged in a similar research project on gender-equitable practice and note the times on the recording when various types of classroom activities are taking place. Examples include: whole-group discussion (minutes 45–60 on tape 3), small-group discussion (minutes 22–30 on tape 1), groups of students engaged in an investigation (minutes 10–20 on tape 2), and students working individually (minutes 15–30 on tape 3). Once you’ve identified various clips, return to the clips you think illustrate your best (or worst) practice and evaluate how equitable your practice was in each clip.
You can also evaluate the practices of students to determine how well they are appropriating the norms you are developing, but we only recommend doing this when you are confident you are modeling desirable practices. Some common lines of inquiry include, but are not limited to:

*Sharing the floor in discussion.* During whole-class discussions, how many girls talk and for how many minutes? How many boys talk and for how many minutes? Do an equal number of girls and boys talk in your class? Do they talk for an equal amount of time? Who is talking? Is it always the same students? What strategies do you use to try to ensure all students participate over the course of a school day? Are these strategies effective? By what measure are these strategies effective? What might you need to change or modify?

*Equal activity and access.* When you ask students to work in small groups to perform demonstration activities to learn more about a concept, do all students have equal access to the equipment and supplies? How do you ensure boys and girls spend equal amounts of time handling the equipment? How do you determine how much time is necessary for a particular activity or investigation?

*Classroom management.* Do you hold the same expectations for male and female students in terms of behavior, appearance, attitudes and interests, social relations, roles, and occupations? How do you compliment or comment on students? Do you notice you comment or compliment girls on their appearance and boys on their performance? Do you find you admonish girls for speaking out and talking out of turn, but you tolerate it in boys? How might you balance your interactions so that you compliment boys and girls on their appearance (if necessary) and that you compliment both girls and boys on their performance? How might you ensure equal offenses are given equal responses?

*Persistence and perseverance.* Are boys and girls equally persistent when it comes to solving puzzles or problems? Do you find you help girls through difficult tasks and let boys struggle and figure it out on their own or vice versa? How do you support students in developing persistence and perseverance?

*Encourage students to learn, explore, or pursue new interests.* Do you encourage girls to participate in science competitions and contests? Do girls have enough options for academic clubs that support their interests? Do you encourage girls to join science programs outside of school?

Once you’ve identified areas where you feel you need improvement, draft a plan to take action. For example, if you find boys dominate whole-class discussions or the same students talk all the time, create a system to help you monitor and adjust
your practice in action. One easy way to ensure an equal number of boys and girls is to keep track of how many times you nominate each or alternate between boys and girls (if appropriate for the discussion format). For more ideas and resources we recommend two popular federal publications from the National Science Foundation include indices of hundreds of resources related to promoting gender equity in science and engineering broadly:


Not surprisingly, strategies for encouraging girls and promoting gender equity in education are very similar to strategies recommended for use with other underrepresented groups in science, including students with disabilities and racial or ethnic minorities. Up to 87% of elementary school teachers report feeling unprepared to teach science to students with physical disabilities and, as with their uncertainty about girls, up to 70% feel unprepared to encourage participation of students from low socioeconomic backgrounds or of racial or ethnic minorities in science and/or engineering (Banilower et al., 2013). Separate lines of inquiry, similar to those outlined for girls, can be launched for these other populations of students with whom you work (e.g., you can evaluate how often students with disabilities participate in whole-class discussion or whether your patterns of punishment target boys of color more than other students). With the help of students, colleagues, mentors, researchers, parents, and various digital and print media resources it’s fun to learn how to encourage and teach all students. A list of a few recommended resources to help you get started on a path to equitable science teaching is provided on Table 2.2.

**INQUIRY PROJECTS AND TOOLS TO SUPPORT BEING|BECOMING SCIENTISTS**

We conclude this chapter with a set of suggested research projects aimed at analyzing the status quo and reframing the process of being|becoming scientists including:

- Inquiry Project 1: Perceptions of Being|Becoming Scientists
- Inquiry Project 2: Students-Researchers Use E-DAST to Describe and Analyze Their Beliefs
- Inquiry Project 3: Scientists in the Media
- Inquiry Project 4: Discrimination—Elders’ Stories and Reflections

Please write and let us know what you and your students learn from engaging in these projects, how you adapt and modify the various tools provided, and whether you were inspired to create new projects and/or tools.
Table 2.2. Selected resources for equitable science teaching

<table>
<thead>
<tr>
<th>Topic</th>
<th>Digital and print resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching science to students with</td>
<td>Organizations: DO-IT: Disabilities, Opportunities, Internetworking, and Technology: An</td>
</tr>
<tr>
<td>disabilities</td>
<td>international center that promotes the success of individuals with disabilities: <a href="http://www.washington.edu/doit">www.washington.edu/doit</a>.</td>
</tr>
<tr>
<td></td>
<td>Independent Laboratory Access for the Blind: <a href="http://ilab.psu.edu">http://ilab.psu.edu</a>.</td>
</tr>
<tr>
<td></td>
<td>The National Science Teachers Association (NSTA) provides an up-to-date collection of</td>
</tr>
<tr>
<td></td>
<td>resources for making science accessible for all students, including those with disabilities: <a href="http://www.nsta.org/disabilities">www.nsta.org/disabilities</a>.</td>
</tr>
<tr>
<td></td>
<td>Science Education for Students with Disabilities promotes and advances the teaching of</td>
</tr>
<tr>
<td></td>
<td>science for students with disabilities: <a href="http://www.sesd.info/aboutus.htm">www.sesd.info/aboutus.htm</a>.</td>
</tr>
<tr>
<td>status families</td>
<td>Teachers College Press.</td>
</tr>
<tr>
<td>Encouraging racial or ethnic groups</td>
<td>Selected books and articles: Gay, G. (2010). <em>Culturally responsive teaching</em>. New York:</td>
</tr>
<tr>
<td>underrepresented in science and/or</td>
<td>Teachers College Press.</td>
</tr>
</tbody>
</table>
CHAPTER 2

Inquiry Project 1. Perceptions of Being|Becoming Scientists

The aim of this research project is for students to develop and revise their perceptions of what it means to be a scientist, how one becomes a scientist, and who can be a scientist.

As a class, students can create and use a series of interview questions to initiate conversations with others about scientists and to learn more about the perceptions of scientists held by members of their communities (e.g., peers, teachers, parents, relatives, friends). After students interview each other (and/or people in their community) with the interview protocol, they can code the results, discuss their findings, and develop their own positions. They can also extend their research agenda (see Chapter 5 for a more in-depth illustration of this interview format). See Appendix B for the recommended interview protocol.

Inquiry Project 2. Student-Researchers Use E-DAST to Describe and Analyze Their Beliefs

The aim of this research project is for students to describe and analyze their beliefs and assumptions about who can be a scientist.

As a class, students can use the E-DAST to uncover their beliefs and assumptions about whom they think can be a scientist, what scientists do, and where scientists work. After students complete the E-DAST they can code their own drawings (or those of their classmates) and analyze the coded drawings for meaningful patterns. Their findings can be used to stimulate further discussion, reading, and/or investigation.

Administer the Enhanced Draw a Scientist Test (E-DAST) to students. Instructions: Students should not be told in advance they will make multiple drawings.

- Part A. Students should fold a legal-size piece of paper into three equal portions. Provide students with colored pencils, pencils, and crayons. Tell the students to keep the paper folded and that they will be drawing on only one of the three folded surfaces.
- Part B. Read the following prompt to students and then ask them to draw on their papers:
  Imagine that tomorrow you are going on a trip (anywhere) to visit a scientist in a place where the scientist is working right now. Draw the scientist busy with the work this scientist does. Add a caption that tells what this scientist might be saying to you about the work you are watching the scientist do. (Farland-Smith & McComas, 2009)
- Part C. When they are finished drawing one scientist, students should be instructed to label the drawing with a #1 and then unfold the paper and draw two more
scientists on the same side of the paper as the first using the prompt previously described.

Assist students with coding the drawings for analysis. Show students how to code their drawings using a pencil to mark relevant indicators on their drawings (Table 2.3).

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>I drew a female scientist.</td>
<td>F</td>
</tr>
<tr>
<td>I drew a male scientist.</td>
<td>M</td>
</tr>
<tr>
<td>I didn’t think about whether my scientist was male or female.</td>
<td>N</td>
</tr>
<tr>
<td>The scientist I drew is me.</td>
<td>Me</td>
</tr>
<tr>
<td>I drew an African American scientist.</td>
<td>AA</td>
</tr>
<tr>
<td>I drew a Hispanic (or Latino/a) scientist.</td>
<td>H/L</td>
</tr>
<tr>
<td>I drew a Native American scientist.</td>
<td>NA</td>
</tr>
<tr>
<td>I drew an Asian scientist.</td>
<td>AS</td>
</tr>
<tr>
<td>I drew an Indian scientist.</td>
<td>IS</td>
</tr>
<tr>
<td>I drew a ____________ [fill in ethnicity] scientist.</td>
<td>[create code]</td>
</tr>
<tr>
<td>I drew more than one scientist working together in the picture.</td>
<td>MS</td>
</tr>
<tr>
<td>I drew one scientist working alone.</td>
<td>OS</td>
</tr>
<tr>
<td>The scientist I drew is working in a laboratory.</td>
<td>L</td>
</tr>
<tr>
<td>The scientist I drew is working outside.</td>
<td>O</td>
</tr>
<tr>
<td>Label the type of scientist you drew (chemist, geologist, meteorologist, biologist, veterinarian, etc.).</td>
<td>[name]</td>
</tr>
<tr>
<td>[Add codes as they interest you and your students]</td>
<td>[add codes]</td>
</tr>
</tbody>
</table>

Assist student with a preliminary analysis of the coded drawings. Tally the responses to each of the questions so students can comment on the data as a whole.

- How many of you drew scientists working outdoors?
- How many of you drew scientists working indoors in a laboratory?
- How many of you drew more than one person in the picture (a team of scientists working together)?
- How many of you drew one person in the picture (an individual scientist working alone)?
- How many of you drew female scientists?
- How many of you drew male scientists?
- How many of you drew scientists that were white?
What kinds of scientists did you draw? For example, did you draw chemists, geologists, sociologists, meteorologists, biologists, ecologists, or another kind of scientist?

Help the students reflect on any patterns that emerged from their analysis. For example, if most of the class drew male scientists we could ask: What do you notice about the gender of the scientists you drew? Why do you think most of you drew boys when about half of you are boys and about half of you are girls? Do you think most scientists are male? If so, where do you think you got the idea scientists are male? If not, why do you think many people in the class drew only males?

Inquiry Project 3. Scientists in the Media

The aim of this research project is for students to analyze the science themed print media (books, encyclopedias, magazines, and textbooks) in their classroom library and/or school library.

Figure 2.4. Example of a drawing of a chemist in the laboratory coded using class-designed indicators

• How many of you drew scientists that were \( \text{[fill in ethnicity]} \)?
• How many of you drew yourself as the scientist?
• What kinds of scientists did you draw? For example, did you draw chemists, geologists, sociologists, meteorologists, biologists, ecologists, or another kind of scientist?
Students create a tool, or use the one provided in Appendix C, to learn how scientists are represented in media intended for their consumption. Students can utilize and modify their E-DAST code list for the purpose of text analysis. An example of a completed coding sheet is provided below (Box 2.2. Similar to the

**Box 2.2.**

*Media Analysis Guide: How the authors of the science books and magazines in my/our library represent scientists.*

<table>
<thead>
<tr>
<th>Indicators</th>
<th>No examples</th>
<th>A few examples</th>
<th>Many examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>No scientist (fiction or real) given credit</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Anonymous scientist</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>(“the scientist …”) or “astronomers say…” or “ecologists found …”)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real scientist with a name</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Fictional scientist character is a person</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fictional scientist character is an animal</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female children (fiction or real)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female adults (fiction or real)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female children as scientists (fiction or real)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female adults as scientists (fiction or real)</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Male children (fiction or real)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male adults (fiction or real)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*(Continued)*
Box 2.2. (Continued)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>No examples</th>
<th>A few examples</th>
<th>Many examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male children as scientists (fiction or real)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male adults as scientists (fiction or real)</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>White (Europe; Middle East)</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Black, African American, Caribbean American (Africa or Caribbean)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>American Indian or Alaska Native</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian (China, Cambodia, India, Japan, Korea, Malaysia, Pakistan, Philippines, Thailand, Vietnam)</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other ethnic identity</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working in a laboratory (wet or dry)</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Working outdoors</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working alone</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working with one other person</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Working with a group</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Additional comments:

- *This book is from the “Scientist in the Field” series (Houghton Mifflin Harcourt) and is about the work of the astronomer Alex Filippenko and the people with whom he works.*
- The “child” featured as a scientist in the text is Filippenko
- *The book does not discuss the ethnicity of the scientists featured. Our ethnic analysis is based only on the photos and could be incorrect.*
other inquiry projects discussed here, students’ findings can be used to stimulate further discussion, reading, and/or investigation.

Assist students (as needed) with an analysis of coded texts. Possible questions include: How many of the print media resources in our library feature children (or school-age youth) as scientists? How many feature adults as scientists? How many don’t feature any scientist character at all?

Help the students reflect on any patterns that emerged from their analysis. Possible questions include: What might readers like us learn about scientists from books that list a lot of information, but do not feature any people? What might readers like us learn about scientists from books featuring famous scientists? What might we learn about scientists from books featuring living scientists?

Inquiry Project 4. Discrimination—Elders’ Stories and Reflections

The aim of this research project is for students to learn about any age, gender, ethnic, and/or racial discrimination their elders may have experienced in their school science or everyday science experiences.

Students create an interview protocol or a survey, or use the one provided in Appendix D to learn (1) how their elders experienced school science and (2) how scientists were represented in media for children when their elders were young. Student researchers can work alone or in teams to conduct their investigations and to present their findings to the class and moderate class feedback and responses.

Assist students (as needed) with their presentations. Remind students to tell the audience (1) whom they interviewed, (2) what questions they asked their research associate (RA), and (3) what the research associate actually said in the interview. Presenters can reflect on their impressions or reactions to the RA's responses, but they should not mix their reactions or interpretations with the RA's actual response in a way that might confuse the audience or misrepresent an RA's position or response.

Assist class (as needed) with analysis of the interview data set. Possible questions include:

- How many of our elders liked school science?
- Of those who liked school science, how many thought they were not good at science?
- How many thought science was not for them?
- How many of them remember some type of discrimination (against them or others) based on age, gender, or ethnicity?
- How many did not like school science?
CHAPTER 2

- Of those who did not like school science, how many thought they were not good at science?
- How many thought science was not for them?
- How many of them remember some type of discrimination (against them or others) based on age, gender, or ethnicity?
- Did any of the elders we interviewed recall how adult, child, and/or youth scientists were represented in TV, books, or films?

Help students reflect on any patterns that emerged from their analysis. Possible questions include: Let’s look at the group of RAs who reported they liked science but thought they were not good at science, why do you think they felt that way? Let’s look at the group of RAs that reported discrimination, what types of discrimination did they face? What reasons might people give for discriminating against another person? How could we test our ideas and learn more?
CHAPTER 3

CONTRIBUTING TO SCIENCE

What Is Scientific Knowledge? How Does One Contribute to Science or Scientific Knowledge? Could I Contribute to Science?

So far, we’ve reconstructed science education’s view of science from a discipline perspective and proposed an alternative model from a learner perspective: the Being and Becoming Scientists Today (BBST) framework. We’ve challenged the notion of an ideal scientist and the linear pipeline or pathway to becoming a scientist. Now we are going to reconstruct the idea that concepts, facts, laws, theories, ideas, or skills are knowledge. This reconstruction of knowledge is not new, but we believe it is for elementary education. In Chapter 1, we argued the dominant approach to science education reflects a disciplinary perspective rather than a learner or learner–scientist perspective. In this dominant approach, the body of knowledge typically refers to objects and things we know and remember. Yet we know from experience knowledge is more than this. Just having or possessing facts, information, skills, rules, and so on, is not enough—taking action with them is what matters and makes knowledge. When we say we know something, what we mean is that we are poised to take action with a particular tool(s) for thinking or learning (e.g., concepts, explanations, norms, skills) to do intellectual work, such as pose, define, teach, or solve a problem.

Educators often present knowledge as a list of information, explanations, facts, ideas, laws, concepts, theories, schema, rules, norms, social practices, skills, and algorithms to be remembered or memorized, coupled with images of idealized scientists as discussed in Chapter 2. This approach makes it hard for learners to see how they can contribute, to become a player, in any knowledge game, whether it is science, philosophy, art, history, mathematics, social studies, cultural studies, or music. In this memory-based mode of knowing, learning is viewed as acquisition and is usually structured as peripheral participation through reproduction and repetition. We argue for an alternative. If, instead, we present concepts, explanations, norms, and skills as tools for thinking and learning (i.e., for problem solving) it makes it easy for learners to see how they can contribute by questioning, making, and modifying these types of tools. Learning in this tool-based model is consistent with our view of collaborative transformative practice, which leads development and contribution.

Contributing to scientific knowledge is not something we typically think primary school learners (or teachers) can do. Undoubtedly, as the new word scientist became associated with an exclusive club of professionals, the opinion grew that only this
group could contribute to scientific knowledge. Therefore, similar to other chapters, the questions of this chapter—“How does one contribute to scientific knowledge?” and “Do I enjoy the work of science?”—appear to be questions relevant to accredited, career scientists rather than young children and their teachers. However, if we envision contribution to include self-development and community development (Stetsenko, 2008), rather than as a distant endpoint achievement of an individual learner as shown in Figure 2.3, then there are unlimited pathways to create sites of contribution for learners of all ages and interests. Every time a child engages in play or exploration she is creating something new and changing her environment. Every time she shares and forms thoughts and ideas together with her teachers and peers she might be making one of us create, think, laugh, doubt, or wonder. It is important we as educators consider what constitutes a contribution and how one contributes to science. First, let’s look at how scientific knowledge is presented to learners.

Revealing Myths about Knowledge

Every science book or magazine we give a child, every hands-on activity or demonstration we ask a child to perform, and every science video clip we show, contains an extraordinary amount of expository writing—assemblies of facts, ideas, theories, laws, and concepts. Usually, the information is simply stated from a single perspective without context as though it is unquestionably true. Using the phrase of psychologist Ellen Langer (1997), it is “mindlessly learned.” What would happen if we questioned these texts with our students? How often do we pose such questions? What would our teaching look like if we expected our students to question these texts?

We can think of nonfiction texts used in science (e.g., books, magazines, videos, or lesson plans) as stories or narratives assembled by an author, who probably assembled them from another author or perhaps from the original authors of the investigation used to establish the fact, idea, or method. We call these tertiary, secondary, and primary sources respectively. All these authors are participating in and contributing to the scientific enterprise in a specific way, by transmitting exciting achievements in learning that have become useful tools for thinking. But in the process they are often also reproducing a variety of myths about knowledge and knowledge production.

- Myth 1. Scientific knowledge is a “stockpile of facts” (e.g., Barnes, 1974).
- Myth 2. There are right and wrong answers (e.g., Asimov, 1988; Langer, 1997).
- Myth 3. There are specific procedures to use to solve particular types of problems (e.g., Barnes, 1974).
- Myth 4. A single crucial experiment can settle a debate between theories (e.g., Barnes, 1974).
- Myth 5. Extraordinarily intelligent people discover scientific facts, ideas, methods, theories, and laws. These people are usually men, usually white, and usually
termed Eurocentric or Western. This implies would-be readers are unlikely to become scientists or to contribute (e.g., Barnes, 1974; Langer, 1997).

To illustrate some ways these myths are propagated, we’ve gathered a few excerpts from resources that might be found in a science teacher’s library, and we’ve labeled or coded them with the corresponding myth(s) we believe each is promoting or has the potential to promote. There is nothing wrong with the content of these sources (for the most part) and they should be considered reliable sources in terms of the facts they portray. The myths refer only to the ways the facts are portrayed.

**Box 3.1.**

*Book Excerpt*


Sir Isaac Newton was probably the greatest scientist and mathematician who ever lived, but Newton did not think there was any limit to speed. It was Albert Einstein who showed us that nature does have a speed limit. It is the speed of light—300,000 kilometers per second (186,000 miles per second). *(Myth 1, Myth 2, Myth 5)*

Sir Isaac Newton (1642–1727) was the first person to really understand motion. His success was due to his ability to think about what motion would be like without friction and without gravity. *(Myth 4, Myth 5)*

Most of the motions we find on earth involve friction. Friction occurs when two surfaces rub against one another. If you roll a ball slowly across the floor, the ball’s speed decreases and eventually it stops. It stops because the friction between the ball and the floor pushes against the ball and reduces its motion. *(Myth 1, Myth 2, Myth 3)*

**Box 3.2.**

*Television Show Excerpt*

Bill Nye the Science Guy
Motion Episode (season 5, episode 20)

*Nye:* Now take a look at this. This is an air track. When the pump is running, air comes out of these little holes *[a camera close-up shows a string telltale blowing]*. And it can support the weight of a scooter like this one *[places the scooter on the air track]*.

*(Continued)*
CHAPTER 3

Box 3.2 (Continued)

Nye: Now, when I place the scooter on the track and let go of it it just sits there. And doesn’t move. Unless, I give it a push. And it keeps moving unless I give it another push [Nye demonstrates with the scooter] or it hits the other end of the track or maybe another scooter [Nye demonstrates by adding another scooter so that the two collide and go to opposite ends of the track]. Now, here’s the thing, if we had enough track and enough air, the scooters would keep scooting forever! There’d be nothing to slow them down, well, hardly anything. So when something’s at rest or sitting still it stays sitting still unless acted on by an outside force and when something’s moving, it keeps moving unless acted on by an outside force.

[The image cuts to video clips of football players colliding and two trains colliding are shown as Nye repeats in a voice over “outside force” “outside force”].

Nye: This is true of everything you can touch and see.

Nye: As you may know-

[The introductory clip voice over is played back, “Inertia is a property of matter.”]

Nye: Inertia is a property of matter.

(Myth 1, Myth 2, Myth 3, and Myth 4)

Box 3.3.

Lesson Plan Excerpt

From the Rules of Forces and Motion lesson plan (Burris, n.d.)


Procedures

Talk about the concept of motion. How do objects move? A good way to introduce this topic is to review Forces and Motion. (Myth 1, Myth 2, Myth 3)

After watching the program, discuss the different types of forces at work in the world. How do they help or hinder motion? Ask students to describe examples of gravity and friction. (Myth 2)

(Continued)
We have presented only one of several ways we might categorize the statements in these excerpts as myths about knowledge production. Do you agree or disagree with our categorization? How would you code these excerpts using the myth categories we provided? Can you think of other myth categories or assumptions about knowledge and knowing that might be myths? How do we bust these myths? For the last question, we can start by asking where they come from and then propose alternatives.

**Sources of Myths about Knowledge**

To understand the common myths about knowledge, let’s start by trying to define scientific knowledge. What is scientific knowledge? In Chapter 2, we discussed the recent invention of the word scientist to describe a small group of professional men viewed as men of science or cultivators of science in general. It is important to note the term scientist came on the heels of an evolving definition of the word science in the 1700s and 1800s.

According to Sydney Ross (1962), “Science entered the English language in the Middle Ages as a French importation synonymous with knowledge. It soon gained the connotation of accurate and systematized knowledge” (p. 66, latter emphasis added). In other words, science was synonymous with knowledge and the phrase we use today, *scientific knowledge*, would be considered redundant. This view lasted...
into the mid-19th century. For instance, “natural philosophy” was synonymous with “natural science,” and “moral science” was synonymous with “moral philosophy,” and these titles were used interchangeably. By the 18th and early 19th century in England, however, the word science had expanded to include two accepted meanings in use:

- Science is *any* knowledge *acquired by study*, or *any* skill *acquired by practice* (Ross, 1962, p. 68, emphasis added).
- Science is *any kind of knowledge acquired by observation or experiment* (a view proposed by Isaac Newton) (Ross, 1962, p. 69, emphasis added).

The theory of knowledge embodied in the second definition is what has since been further expanded and become synonymous with the notion knowledge is a stockpile of concepts, explanations, norms, and skills generated by a particular method (e.g., Barnes, 1974). This is the body of knowledge as viewed from the disciplinary perspective represented in the three-legged stool metaphor of science introduced in Chapter 1 (Figure 1.1).

Outside university classrooms during this period, the terms science and philosophy continued to be used interchangeably. Within those classrooms (including textbooks, journals, articles and lectures), however, there was a trend toward using philosophy to refer to theological and metaphysical branches of knowledge and using science to refer to the experimental and empirical branches of knowledge (Ross, 1962, p. 69). In other words, science, the term previously used for the practice of creating all knowledge, was increasingly being applied only to knowledge generated by professionals who were using experimental and empirical approaches to the production of facts and explanations about the world (as opposed to theoretical approaches or inductive reasoning). Limiting the use of the word to a single branch of knowledge bolstered the opinion that the only true knowledge was generated by physical scientists’ explorations of the material world (Ross, 1962, p. 70).

This opinion, knowledge is legitimate only if it is generated through experimental or empirical methods, implies all other knowledge is illegitimate. This is a fairly recent but pervasive belief in our culture. This means all other knowledge is false, untrustworthy, or illegitimate, including: knowledge generated by nonprofessionals, indigenous peoples, and other outsiders; knowledge generated through anecdotal personal experience, hearsay, and induction; knowledge produced by ethical or moral arguments; and knowledge generated in the humanities, including history, literature, music, visual arts. We hope, this sounds absurd to you, but let’s consider some of the ramifications of the opinion that true knowledge only comes from scientists.

*Freedom from teleological and supernatural explanation.* Splitting natural philosophy from theology and metaphysics created a clear position regarding divine intervention and control over natural phenomena and events—that is, natural philosophers could not evoke supernatural beings or powers in their explanations...
of the world. Magical thinking was not allowed in scientific knowledge production and this was considered by many to be a major achievement. With this restriction on natural philosophy came a new kind of uncertainty, but also room for developing human agency. Humans no longer had to submit to superstitious rituals or accept that supernatural entities controlled their fate.

Power to act. Causal explanation grounded in empirical observation and experimentation was a hallmark of knowledge produced in the physical sciences. With causal explanation came power and control over our personal present and future, as well as the present and future of the world around us.

Knowledge cultures. Inventing scientist as a new career option was initially thought degrading to the work of the “men of science,” but the creation of an exclusive group of professional men, combined with the notion the knowledge they produced is the only true knowledge of the world, resulted in what Knorr-Cetina (1999) referred to as the “premier epistemic culture” in the world. An epistemic culture produces tools for creating, justifying and warranting knowledge production and with it the potential for power (leadership) and authority.

Hierarchy and alienation. A hierarchy of knowledge value was created when empirical methods of knowledge production were viewed as more valuable or favorable than all other methods because of the “tangible benefits derived from [science]” (Ross, p. 69). Historian Barbara Tuchman (1981) challenges the problem with valuing science over other ways of thinking in her pithy response to the question of whether or not we can learn from the lessons of history:

If history were a science, we should be able to get a grip on her, learn her ways, establish her patterns, know what will happen tomorrow. Why is it that we cannot? The answer lies in what I call the Unknowable Variable—namely, man. Human beings are always and finally the subject of history. History is the record of human behavior, the most fascinating subject of all, but illogical and so crammed with an unlimited number of variables that it is not susceptible of the scientific method nor of systematizing. (p. 247–248)

Although we might still argue one of the great achievements of talking and thinking scientifically was to free people from the whims of irrational supernatural beings, we also need to resist devaluing all other forms of knowledge by the unreasonable insistence on scientific methods as the sole means of knowledge action and production. For instance, one reason studying history is valuable is, as Tuchman claims, because it teaches us the limits of our ability to predict the future.

Authority. It has become acceptable to pay attention to other ways of knowing only after a scientific authority gives credence to these approaches. One high profile case illustrates the power of this authority.
The Dalai Lama believes “mental and physical realms have an equal claim on reality. That is, mental constructs science considers imaginary are, to Buddhists, objectively real and perceptible” (Geirland, 2006) and therefore, can be trained and controlled like any other physical entity. The Dalai Lama also believes in the authority of science and argues if neuroscientists could study and describe these mental realities scientifically and separate them from their religious context, then these mental constructs will be considered reality and widely adopted by non-Buddhists. When a neuroscientist invited the Dalai Lama to the Society for Neuroscience’s annual meeting, however, many scientists protested in fear that allowing the religious leader to talk would be seen as approval by career scientists to conflate science and religion in school classrooms (Geirland, 2006). In addition, Chinese scientists living and working in America further argued allowing this political leader to talk would be seen as an “invitation to lend scientific legitimacy to Buddhism and press the Chinese government to ease up on Tibet” (Geirland, 2006). The Dalai Lama spoke, but many boycotted the conference. Today neuroscience research on the possible benefits of meditation is growing and comprises a contemporary example of translating ancient practices into science vernacular and, in the process, gaining the interest and acceptance of scientific authorities (e.g., Ricard, Lutz, & Davidson, 2014). This reflects the belief scientific authority is powerful enough to transform what some view as magical or symbolic rituals into acceptable practices.

Endangered and extinct knowledge. In the wake of accepting the existence of one true body of knowledge, came the inevitable loss of other ways of knowing. Today, as the languages of indigenous people are lost (or absent in schooling) they are scrambling to recover decimated practices and knowledge systems including healing practices, sustainable living practices, and conservation practices among others (e.g., McKinley 2005). Obvious solutions to very clear and present dangers are caught up in arguments about data, proof, and certainty (pseudoscientific arguments) instead of compassion, human rights, protection, and survival.

Each of these ramifications of the opinion true knowledge only comes from scientists carries broad implications for individuals and society. What are the implications for teaching and learning the view that the facts and skills of science are the only true knowledge? When facts and skills are viewed as what philosophers call justified true beliefs that can be transmitted between and acquired from individuals, this creates a specific kind of teacher–learner relationship. Namely, when knowledge is treated as a noun or an object, and knowing means having or possessing these objects in one’s brain, then the key goals of learning science become building memory: storing specific facts and instructions for performing specific skills in our brains for random access (e.g., Achieve, 2013). Reformers object to and avoid this type of teaching, but we believe until our attitudes and portrayals of knowledge change, we will live in endless cycles of empty claims of “best curricula” and “this works.”
Redefining Scientific Knowledge as Part of Myth Busting

We propose an alternative to the view knowledge is a stockpile of facts. We call for a theory of knowledge that embodies practice and treats knowledge as a verb or an action—a means of “collaboratively transforming the past in view of present conditions and future goals” (Stetsenko, 2008, p. 489). The key goals of learning science from this perspective become knowing the past in order to be able to transform the present, and emphasizing a vision for the future from which the past can be known. In other words, not only is knowledge a form of action, its purpose is for action. Knowledge and knowing are synonyms for the actions we take, and they refer to “what procedures are efficacious in any given rational enterprise, on what conditions, and for what practical purposes” (Toulmin, 1999, p. 62). This does not mean there are no facts and skills to be learned; it just means these are not examples of knowledge. Concepts, explanations, norms, and skills are all cultural tools (i.e., tools for thinking, tools for learning) that learners use in knowledge-acts. In other words, we propose knowledge be viewed as for and as action and be renamed knowledge-act to highlight this meaning and distinguish it from dominant meanings.

Making the transition from thinking about knowledge as an object (e.g., concepts, explanations, norms, skills) to thinking about knowledge as action is a difficult one to make in a world where the notion of knowledge as facts pervades every aspect of our lives. Viewing concepts, explanations, norms, and skills as tools for thinking and viewing knowledge as action (knowledge-act), however, is consistent with the positions of Vygotsky, Dewey, Freire, Bruner, hooks, Kincheloe, Steinberg, McLaren, Delpit, and many other authors typically introduced in teacher education foundation courses and/or child and adolescent development courses. We recommend revisiting major works by these authors as you make this transition to see how they’ve treated knowledge in similar ways.

Tools for Thinking, Tools for Learning

The concept of cultural tool was developed initially by Lev Vygotsky (1987), who viewed the invention and use of signs as meditational means for problem solving (e.g., to remember, compare something, report, choose). Cultural tools include both physical and mental tools, and we refer to these as tools for thinking or “tools of the mind” (Bodrova & Leong, 2007). Examples of common tools for thinking are facts, concepts, norms, and social practices. We find Victor Kaptelinin, Kari Kuutti and Liam Bannon’s (1995) definition of cultural tools well detailed:

Tools shape the way human beings interact with reality …. Tools reflect the experiences of other people who have tried to solve similar problems at an earlier time and invented/modified the tool to make it more efficient. This experience is accumulated in the structural properties of tools (shape, material, etc.) as well as in the knowledge of how the tool should be used. Tools are
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created and transformed during the development of the activity itself and carry with them a particular culture—the historical remnants from that development. So, the use of tools is a means for the accumulation and transmission of social knowledge. It influences the nature, not only of external behavior, but also of the mental functioning of individuals. (p. 192)

Based on this definition viewing concepts, explanations, norms, and skills as tools for thinking instead of as knowledge means we acknowledge they:

• Shape the way we interact with reality (e.g., how we perceive, act, interpret).
• Were structured by the experience of previous generations of problem solvers.
• Are intended to be used.
• Might be modified.
• Carry remnants of their developmental history.

When adopting a fact or other type of tool such as a concept, explanation, norm, or skill, we should be curious and knowledgeable about its intellectual origins, history, and development. What assumptions have been tested and which have not? What might the fact obscure as we conduct our work and what does it appear to clarify? In what context was the fact developed (e.g., in contrast to what alternatives)? What was its intended use? If we decide to develop a new fact, we need to be clear about why we feel we need to create something new. Why are the existing facts unsatisfactory? How would we describe all the elements of our new fact using this notion of tool as a guideline for communicating our fact to others? When we look closely at the current dominant notion of knowledge as a stockpile of facts and see its obvious flaws, we can see the power of switching to the notion of facts as tools for thinking and learning. Let’s explore the implications of this view.

First, let’s examine a few tiny grains of knowledge from the mythical stockpile of facts that comprises everything we know about the world as generated through experimental or empirical methods. On Table 3.1, we have selected three facts from the stockpile and compared their status at two points in time. What we learn at any point in time is there are many true facts within the stockpile of scientific facts that are not entirely correct. They reflect varying degrees of “wrongness” and “rightness” (Asimov, 1988) which are revealed in use over time. In each of these examples is an exciting and complex human story of changing a tool for thinking.

Ecology. First described in a written record by Alfred Moeller in 1893, leaf-cutter ants of the Amazon make their nests in underground chambers (Wilson, 1971). Some of the ants are in charge of foraging for leaves, which they cut from the vegetation surrounding the nest. They cannot eat these leaves directly, because they are filled with toxic chemicals produced by the plant as protection against grazers. Instead, they bring the leaves back to their nests, where other ants chew them up and feed them to a fungus that digests the leaves, poison and all. In the process the fungus swells with proteins and sugars as it digests the leaves. The ants then eat the nutritious fungus.
Table 3.1. Examples to illustrate that the stockpile of facts changes over time

<table>
<thead>
<tr>
<th>Years</th>
<th>Fact</th>
<th>Years</th>
<th>Revised fact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1893–1998</td>
<td>Ecology: belief that Amazonian leaf-cutter ants are so adept at weeding out disease causing pests that their fungus gardens remain disease and pest free</td>
<td>&gt;1999</td>
<td>Ecology: belief that leaf-cutter ants carry antibiotic producing bacteria on their bodies that inhibit an aggressive fungus pest present in the gardens</td>
</tr>
<tr>
<td>1930s–1998</td>
<td>Astrophysics: belief that the expansion of the universe, described by Hubble in 1929, had to be slowing down due to the attractive force of gravity, which pulls all matter together.</td>
<td>&gt;1998</td>
<td>Astrophysics: belief that the universe is expanding and accelerating. The cause is “dark energy.” Belief that the majority of the universe is dark energy (about 68%) and dark matter (about 27%), not the matter and energy we can see (about 5%). The nature of dark matter and dark energy are not yet well understood, neither is the fate of the universe.</td>
</tr>
<tr>
<td>~1950s–1990</td>
<td>Climate science: belief that the Earth’s oceans are the major carbon sink absorbing the excess carbon dioxide produced by humans burning fossil fuels. The implication is that deforestation does not matter much.</td>
<td>&gt;1990</td>
<td>Climate science: belief that the Earth’s lands and oceans absorb approximately equal amounts of carbon dioxide. The implication is that deforestation has a greater effect than previously thought.</td>
</tr>
</tbody>
</table>
In other words, these ants maintain fungus farms. One hundred years of research on these farms led most ecologists to conclude these ant farmers are so good at weeding out other types of fungus their farms are disease free.

Cameron Currie, a graduate student, didn’t think the ants could possibly be that good at weeding, so he investigated further. In a documentary featured in the PBS television show *Evolution*, Currie was interviewed about his work (Benyo, 2001). He explained how other researchers discouraged him from conducting any research into diseases of ant colonies when he first started: “I actually had some people tell me that looking at diseases in the ant garden was, was kind of a silly project. That the ants maintain their garden free of diseases and so why would you be going there to look for diseases? So I went out and collected ant colonies and isolated pieces of the garden to see what was there other than the fungus the ants cultivated.”

The narrator of the video explained how Currie cultured 1,500 samples of fungus from the gardens and found an aggressive fungus kept showing up in the cultures: “When he removed the ants from the nest he saw the mold devastate the forest in a matter of days.” Currie did show that the ants had at least one fungus pest in their gardens (and a very potent one at that). Now, his next problem was figuring out how the ants kept this other fungus in their nest completely under control, to the point that no other investigator had detected it. During his studies of these ants, Currie had noticed some of the ants’ body parts were covered with a waxy white coating and the bodies of the ants that worked deep in the garden were almost entirely covered with it. Working in collaboration with his advisor, Ulrich Mueller, they figured out it was made up of tangled mats of bacteria, the same bacteria that produce many of the antibiotics we humans use to fight off infectious diseases.

In the interview, Currie reflected on his thinking at the time: “I remember my graduate advisor and I were laughing, thinking that, um, wouldn’t this be exciting if these ants have effectively been using these bacteria for the production of antibiotics for millions of years, when humans only discovered this 60 years ago? And we thought, at the time, that maybe this was a bit far-fetched.” Even though Currie and Mueller had some doubts the ants were carrying colonies of bacteria on their bodies as a source of antibiotics to fight off the aggressive mold present in their nests, this is exactly what was happening.

For about 100 years the fact that leaf-cutter ant colonies were disease free was accepted as true, until Currie and Mueller doubted the plausibility of the claim. Not only does their work illustrate the complexity of biological relationships it also demonstrated how our knowledge of these relationships changes over time (Currie, Mueller, & Malloch, 1999).

**Astrophysics.** Albert Einstein favored a model of the universe that was static and not expanding, but his equations of general relativity supported a variety of possible realities. Georges Lemaître argued the same equations favored an expanding universe model—that is, the universe has been expanding since a Big Bang, and still is. It was Edwin Hubble who did the astronomical investigations to show Lemaître’s
theory was true. Hubble visualized distant galaxies and found the farther they were from us, the faster they were traveling away from us. In other words, the universe is expanding (Hawking, 1996; Netting, 2014). What is the nature of that expansion?

Two major camps of physicists emerged to explain Hubble’s observation, but the theories proposed by both of them depended on gravity. The closed-universe camp argued gravity is strong enough to slow down the expansion to zero (to the point of stopping) and then reverse the process, leading eventually to a “big crunch” as the universe collapses on itself. The Continually–Expanding–Universe camp argued the expansion is slowing, but the expansion will never get to zero, so the universe will expand forever.

These were the major hypotheses held by most physicists for about 60 years until the mid-1990s, when they learned something strange. By studying the most distant observable light, Saul Perlmutter, Brian Schmidt, and Adam Riess noticed very distant supernovas were speeding away from us even faster than they should be by either current model. They weren’t slowing down—the rate of expansion was accelerating. That observation made no sense based on the classic understanding of gravity. How could the expansion be accelerating against the force of gravity? That type of acceleration would require some force acting on the whole universe. The team didn’t know what that could be, and they couldn’t detect it, so they proposed the existence of a dark energy, a kind of energy we’ve not appreciated until now. This energy is repulsive, unlike gravity, which is attractive. Over large distances, the repulsion is greater than the attraction of gravity, which explains why the expansion of the universe is accelerating.

This is a relatively new idea and has changed many astrophysicists’ view of the universe. By figuring out how much energy it takes to make the matter in the universe behave as it is (expanding), one can estimate how much dark energy is necessary (in addition to the known energy) to drive that acceleration. Using calculations like this, physicists currently estimate roughly 68% of the universe is dark energy, and many teams are working on trying to understand more about what it is. This shift in thinking radically altered our view of the world, to the point where what we thought was the normal majority of matter and energy has become the rare exception of matter and energy of the universe. The Earth and everything ever observed with our instruments, so-called normal matter, adds up to less than 5% of the universe. These investigations have profoundly transformed how we understand the universe, and the scientists were awarded a Nobel Prize for this discovery in 2011. This example illustrates how new observations can lead to changing hypotheses.

Climate science. The greenhouse effect was proposed in the early 1800s. By 1895 a Swedish scientist, Svante Arrhenius, suggested the excess carbon dioxide produced by coal-burning factories might trap more heat near the Earth’s surface, but he had no way of testing this idea. It wasn’t tested until the 1950s, when Charles Keeling put a carbon dioxide monitor on top of an extinct volcano in Hawaii in 1958 and let it take measurements of the amount of carbon dioxide over a period of several years.
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Keeling found that amount of carbon dioxide in the air was rising, in contrast to the common assumption of the time, which was that the oceans were soaking up most of the excess carbon dioxide humans were putting into the air from the carbon fuels consumed by buildings, industry, cars, trucks, and power plants.

As climate science expanded some scientists, including Dr. Inez Fung, were interested in tracking the sources and sinks in the Earth’s carbon cycle (Skelton, 2005). Fung pioneered what is now known as earth systems modeling, where the complex chemical, physical, and biological reactions on Earth are transformed into mathematical equations. These are used within computer programs designed to predict the evolution of the Earth’s climate. While other scientists were certain the oceans were the major carbon sink on Earth, Fung insisted on tracking all the biogeochemical cycles related to carbon, including: the carbon cycle, the methane cycle, wind patterns, and all possible carbon sinks such as oceans, forests, and deserts.

By the early 1980s Fung had created the first three-dimensional global carbon model linking the atmosphere and the biosphere. With two other NASA scientists, Jim Tucker and Katie Prentice, she showed how carbon moves between plants and the atmosphere in a regular seasonal cycle (you’ve probably seen the compilation of satellite images from Fung’s work in the popular press, which show the seasonal fluctuation of carbon matched to the seasonal fluctuation of foliage (e.g., NOAA/ NESDIS Center for Satellite Applications and Research, 2014).

Meanwhile scientists like Jim Hansen were discovering climate change was already a measurable reality, not merely a possibility for the future. Based on his group’s work, more data were needed to track carbon in the atmosphere (where it was, how fast it was increasing), so Inez Fung, Pieter Tans, and Taro Takahashi set out to determine the best places to set carbon dioxide monitoring stations using improved carbon models based on Fung’s recent work. When they added their new data on the fossil fuel sources and the ocean uptake of carbon dioxide, the model showed there should be much more carbon dioxide in the northern hemisphere (where there are the most sources of human-produced carbon dioxide) than had actually been measured in the field. They wondered where the newly released northern carbon dioxide was going, so they started looking for sinks or places where carbon is absorbed.

At the time, most scientists believed the southern hemisphere’s oceans were soaking up much of the carbon dioxide. But when Fung, Tans, and Takahashi increased the amount of carbon absorbed by this sink in their computer model, they found it increased the amount of carbon dioxide in the northern hemisphere atmosphere, which again didn’t match the known records from empirical measurements. When they programmed the northern ocean sink to absorb more, that didn’t work either. Besides, scientists had gathered plenty of data to show the northern oceans were not absorbing as much as Fung and her colleagues were telling the model to absorb.
At that point, “We had no choice,” Fung said, “but to put the sink on land in the northern hemisphere. That’s exactly the place no scientist thought it could be. When our article was published in *Science* magazine, my friends called me up and said, ‘You’re wrong.’ ‘That may be,’ I said, ‘but you’ll have to prove it to me.’ And they couldn’t. There was no data” (Skelton, 2005, p. 70). Ultimately, no one could prove Inez wrong—a huge land sink in the northern hemisphere was soaking up the planet’s excess carbon dioxide. “That paper was a turning point in the study of the carbon cycle,” Fung said. “Before then, oceanographers thought the oceans were responsible for removing fossil-fuel carbon dioxide from the atmosphere. They thought that the land did very little. But here we were saying that the land and the oceans absorb approximately equal amounts of fossil-fuel carbon dioxide” (Skelton, 2005, p. 70). Fung and her colleagues reconstructed an assumption in their field that had been treated like a fact.

* * *

Through these three examples, out of thousands of possible examples, we are attempting to show that when we compare facts at any two points in time over the entire history of scientific knowledge production, we can see progress is made in clarifying our explanations and observations of natural phenomena, but we also see this means any body of knowledge must always be flawed at any point in time. What is the nature of the flaws in the stockpile of facts? Asimov rejects the notion right and wrong are absolutes and explains so-called flaws or wrong facts are usually incomplete or, what he called, “relatively wrong” for a variety of reasons (Asimov, 1988).

If we view knowledge and knowing as part of collaborative transformation practice, and facts (concepts, explanations, norms, skills, etc.) as tools for knowing, thinking, and learning, then Asimov’s observations make a different kind of sense. The reason right and wrong are not absolutes is because there is usually a variety of tools we can apply to a particular problem, and these not only aid our knowledge-acts, they can limit what’s possible. In the case of the Amazonian ants, the ants were good farmers, but without understanding harmful fungi were present all the time, there was no incentive for scientists to look for how the ants kept them in check. In the case of the models of the universe, each model was plausible based on the data at hand. With new observations, however, modifications in the models had to be made and a new hypothesis had to be proposed. Finally, in the case of understanding the climate system, careful modeling of an intricate system made it possible to consider alternatives that had been ignored or rejected.

Just having a tool should not constitute knowing. If the goal of learning is having a fact or skill in the absence of taking action, then what is the point of learning? Knowing must refer to the act of using the tools (or creating new tools) in problem-solving actions.
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How Is Our Portrayal of Knowledge and Knowing Relevant for Teaching and Learning Science?

If a learner believes she has to learn a series of facts about the natural world and earn certification before she can be a scientist, then she will be forced to trust the actions and decisions of others without understanding their origins. She will see no point in trying to contribute (or even the possibility of contributing) to science until she has completed the prerequisites and obtained a particular degree. As she continues through schooling that reinforces this trajectory, she may get discouraged with the prerequisites and drop out, or worse, she might claim to be “not good at science.” It is imperative to be clear about the theory of knowledge we present to learners of all ages if we are to free them and ourselves from the view that only people with good memories for decontextualized facts, concepts, and algorithms can possess scientific knowledge. By viewing concepts, explanations, norms, and skills as tools, learners can recontextualize these tools, humanize them, and see them as part of larger, communal problem narratives. By viewing knowledge and knowing as the action of using these tools to “collaboratively transform the past in view of present conditions and future goals” (Stetsenko, 2008, p. 489) learners can see how they are taking action every day to control and shape the nature of the contributions they make to their self-development and community development.

Myth-Busting Tools for Thinking or How to Use the Ideas of Tools for Thinking and Knowledge-Acts When We Have to Work within the Context of an Educational System That Outlines Knowledge as Learning Standards for Science

Employing a phrase such as tools for thinking, tools of the mind, tools for learning, or tools for knowing requires altering a habit. Young children are learning new words and phrases every day, and these are not especially complicated if they are derived with the students and employed routinely. Like other words and meanings, this use of the term tools will become commonplace. Unfortunately, the adopter is likely to be the only person in his/her school who uses these phrases until he/she persuades other faculty and administrative staff to try them out as well. However, once in the habit of referring to the content portrayed in a variety of texts as tools and exploring their origins and utility, it becomes easier to make these texts more accessible because it creates a space where we, our professional peers, our students, and their families can critique, question, and explore.

Let’s look back at the excerpt from the book we used for myth-revealing exercises (Experiments with Motion, Box 3.1). This expository text provides a lot of information in quite a small space. Every sentence can raise profound questions and provide tools for thinking. Below, we unpack the first nine sentences of the book in order to illustrate some myth-sustaining tools for thinking learners might construct from the text without assistance from an instructor who models how to ask critical questions. These tools for thinking are examples of those that sustain popular myths
about knowledge and knowing. We also propose a series of critical questions that could be used to mediate the text in order support alternative tools for thinking that bust the common myths about knowledge.

**Line 1.** “Sir Isaac Newton was probably the greatest scientist and mathematician who ever lived, but Newton did not think there was any limit to speed” (Gardner, 1995, p. 7).

*Myth-sustaining tools for thinking.* It appears to be acceptable to judge and label people (e.g., great, bad, mean, kind). It appears to be acceptable to simplify people’s thinking and present it without a meaningful context.

*Critical questions.* Why does this author consider Isaac Newton the greatest scientist and mathematician who ever lived? What is the point of expressing that opinion? Newton may have had great ideas and made great contributions, but does that mean he was great? Why does the author tell us Newton was great and then tell us Newton was wrong about something? Is the point great people can be wrong? What might have influenced Newton’s ideas about motion and speed at the time? Why do we care about speed limits?

*Myth-busting tools for thinking.* It is unacceptable to judge and label people, but it is acceptable to label their actions and works. No one works in a social, cultural, or historical vacuum and it is important to recognize when someone’s contribution is being represented that way and why.

**Line 2.** “It was Albert Einstein who showed us that nature does have a speed limit” (Gardner, 1995, p. 7).

*Myth-sustaining tools for thinking.* When a person makes a mistake there is always another person who will come along and correct it. It is acceptable to rank people by their perceived greatness. For example, someone who corrects another person can be viewed as greater or better than the person who made the mistake.

*Critical questions.* Because Einstein figured out what Newton could not, does that make him better than Newton? Why did Einstein even look for a speed limit?

*Myth-busting tools for thinking.* Curiosity about a person’s object–motive can help learner’s understand problem-solving actions undertaken by others. It is more important to realize why a particular contribution is great rather than to label and rank individuals.

**Line 3.** “It is the speed of light—300,000 kilometers per second (186,000 miles per second)” (Gardner, 1995, p. 7).

*Myth-sustaining tools for thinking.* Facts represent certainty. Facts are true.
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Critical questions. Does the speed of light vary at all, even slightly? Could it be 186,000 miles per hour one moment and 186,001 miles per hour another moment? The fact refers to the speed of light in a vacuum. What’s the speed of light in air, in water, or in other conditions? How do we know there is nothing faster? Scientists have discovered dark energy and dark matter—how fast can they move? Even if we eventually found Einstein’s restriction on speed was wrong, would we ever find Newton was right and there is no limit to speed? Why do we care to know the speed of light?

Myth-busting tools for thinking. Things we call facts are stable, socially constructed cultural tools agreed upon as true. Facts can be used to create new questions, wonderings, and thought experiments. Facts, however, only have power in science when they are embedded in a theory. Which is why we should attend to critical questions.

Line 4. “Sir Isaac Newton (1642–1727) was the first person to really understand motion” (Gardner, 1995, p. 7).

Myth-sustaining tools for thinking. A single person generates facts, theories, laws, and so on. Only people who record and publish their understandings (and have these publications maintained and curated by future generations) should be the ones who deserved to be remembered as discoverers.

Critical questions. What does it mean to understand motion? How do we know Newton was first? What if someone else figured it out, but didn’t write it down? Do we understand motion completely, even now? (No; there is still much to be discovered at the quantum and astronomical levels regarding the behavior of matter and energy.) Why do we care to understand motion?

Myth-busting tools for thinking. Whenever a single story is presented it is important to learn more about the origins of the story. The history can be a fascinating study in itself, especially as it reveals multiple stories in context.

Line 5. “His success was due to his ability to think about what motion would be like without friction and without gravity” (Gardner, 1995, p. 7).

Myth-busting tools for thinking. Success can be attributed to innate or inherited ability.

Questions. Where did Newton get this ability? Is the author talking about imagination? Is imagination something we can practice and improve, or is it something we possess? What is friction? What is gravity? Why do we care to describe motion without gravity?

Myth-busting tools for thinking. Success should be attributed to a dynamic system of interactions and circumstances including the act of constructing
historical records. Success can also be attributed to the ability to theorize or develop theoretical tools for thinking about the world.

**Line 6.** “Most of the motions we find on Earth involve friction” (Gardner, 1995, p. 7).

*Myth-sustaining tools for thinking.* Facts represent certainty. Facts are true. Facts can be used for making universal claims and generalized statements about the world.

*Critical questions.* What is friction? What motions do not involve friction? Why are we so sure most motions involve friction? Is it fair to generalize? Is friction the same as motion? Why do we care about friction?

*Myth-busting tools for thinking.* Things we call facts are stable, socially constructed cultural tools agreed upon as true. Facts can be used to create new questions, wonderings, and thought experiments. Facts can be used for making universal claims and generalized statements about the world, but we must be cautious of these generalizations and remember how they were made. Uncertainties in the underlying facts would weaken the strength of a generalization built upon them. This caution leaves room to accommodate new observations and ideas and allows for change.

**Line 7.** “Friction occurs when two surfaces rub against one another” (Gardner, 1995, p. 7).

*Myth-sustaining tools for thinking.* Facts represent certainty. Facts are true. Facts can be observed.

*Critical questions.* If most motions involve friction, that means some do not. Are motions that do not involve friction not rubbing against another surface? Where does that happen? What is friction? Is friction the action of rubbing or is it the result of rubbing? Why do we care to know when friction is generated?

*Myth-busting tools for thinking.* Things we call facts are stable, socially constructed cultural tools agreed upon as true. Facts can be used to create new questions, wonderings, and thought experiments. Facts are not observations. When we tell our observation to someone else the verbalization is a representation of an observation. It is not the observation itself. When we claim an observation is a universal regularity it typically becomes a recorded and retold fact.

**Line 8.** “If you roll a ball slowly across the floor, the ball’s speed decreases and eventually it stops” (Gardner, 1995, p. 7).

*Myth-sustaining tools for thinking.* (See Line 7)
Critical questions. What kind of ball? What if the floor is slanted up or down slightly? Why do we care to understand the ball’s behavior?

Myth-busting tools for thinking. (See Line 7)

Line 9. “It stops because the friction between the ball and the floor pushes against the ball and reduces its motion” (Gardner, 1995, p. 7).

Myth-sustaining tools for thinking. Explanations represent certainty and truth. Explanations cannot necessarily be observed.

Critical questions. Is friction rubbing or pushing? If the floor pushes against the ball why doesn’t the ball come up off the floor into the air or travel faster? Why does friction always slow the ball down? What is friction? Is friction a push force? Is friction a force? When we say force are we talking about some magical property someone controls, like Luke Skywalker does in Star Wars? Why do we care about the effects of friction on a rolling ball? (In a more extended analysis of the text we could also ask about other energy losses that are and are not frictional in origin. Those questions would demonstrate that Gardner’s explanation is not an explanation accepted by career scientists).

Myth-busting tools for thinking. Causal explanations, like facts, can be used to create new questions, wonderings, and thought experiments. Explanations are useful tools for talking about what we experience in the world. Explanations require imagination, but cannot employ magical thinking.

We’ve modeled here types of critical questions you and your students can ask after reading any science text. The goals of using these questions are two-fold. The first is to use the questions to help students comprehend the text and to promote further investigation and the second is to promote alternative, myth-busting (and more useful) tools for talking and thinking about knowledge production in science. By trying to generate as many questions as possible about the meaning of the text and the claims the text makes, it becomes easier to recognize what is comfortably known and what is still unknown (to students and to scientists in general). These types of questions are essential for helping students develop the myth-busting tools for thinking they need to appreciate (and seek) details about the social, cultural and historical contexts of knowledge-acts. This is part of what we mean by “keeping the everyday world problematic” (Smith, 1987).

We find identifying the myth-sustaining tools for thinking promoted by the text is a more difficult task than questioning the text because it requires describing the most likely interpretation that could be made from the text. To identify these possible interpretations we start by removing all specificity (proper nouns or specific descriptors). For example, the statement, “Sir Isaac Newton was probably the greatest scientist and mathematician who ever lived” would become “_____ was probably
CONTRIBUTING TO SCIENCE

the _____-est scientist and mathematician who ever lived.” Through this process, we can see the main purpose of the sentence was to label or describe a person—instead of the label “greatest” the label could have been meanest, cruelest, sweetest, saddest, or slyest. When a label is applied in this way, one of the major tools for thinking embodied in the sentence is that it is acceptable to label people. Ask anyone who gets stuck with a label why that practice is unacceptable (e.g., “He’s a slow learner,” “She’s an ELL,” “He’s a procrastinator,” “She’s a brain”). Next, we might look for claims, including exaggerations and hedges that omit important contextual information relevant to the claim. The original sentence has the exaggeration “who ever lived”—a classic device to pique the reader’s interest but does not and cannot reflect a universal reality because such a statement is always dependent on an individual’s perspective. Upon reflection, it seems absurd to label anyone the greatest or worst anything. What’s the point? In summary, to articulate myth-sustaining tools for thinking we look for underlying assumptions and perspectives embodied in the writing that reflect an author’s way of reading the world and making sense of what they see. Recognition becomes easier with practice.

Now we encourage you to try this exercise on the TV show transcript from Bill Nye’s program on motion (Box 3.2) and on the lesson plan for teaching motion concepts (Box 3.3) or another text of your own choosing. How many questions can you generate in response to the text? What myth-sustaining tools for thinking does the text provide for readers? Analyze the critical questions you generated, do they promote myth-sustaining tools for thinking or do they represent alternative, myth-busting tools? How can you adjust your questions to promote specific myth-busting tool creation?

This same analysis can be used on the science learning standards. If we view the standards as a list of useful tools, it empowers us to reflect on their value and utility for posing, describing, and solving problems. When approached this way it is easier to use the standards as a guide, but also to question their relevance, selection, assembly, completeness, and utility. In fact, once we begin to use this approach we find it changes the way we interpret everything we read beyond the venue of science.

Let’s examine the K–5 learning progression for the subtopics listed under “heredity,” which are included in the learning standards for the life sciences (Table 3.2).

Viewing the statements in the middle column as tools for thinking and learning about the world encourages us to learn more about their origins, purpose, and utility. For example, we can ask where these statements came from (e.g., who invented them), why we care to know them, how confident are we in using them for solving problems, what other perspectives about development do they eschew or negate, are they context dependent, and what distinctions are made within and between statements and why. These are universal claims (as are all science standards), which
<table>
<thead>
<tr>
<th>Subtopic</th>
<th>Learning standard (K–5)</th>
<th>Grade level performance</th>
</tr>
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</table>
| LS3.A Inheritance of     | Young organisms are very much, but not exactly, like their parents and also resemble other organisms of the same kind.                                                                                                                                                                                                                               | **Grade 1.** Make observations to construct an evidence-based account that young plants and animals are like, but not exactly like, their parents.  
[Clarification statement: Examples of patterns could include features plants or animals share. Examples of observations could include leaves from the same kind of plant are the same shape but can differ in size; and a particular breed of dog looks like its parents but is not exactly the same.]  
[Assessment boundary: Assessment does not include inheritance or animals that undergo metamorphosis or hybrids.]                                                                                                                                                                                                                          |
| traits                   | Many characteristics of organisms are inherited from their parents. (3-LS3-1)                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                         |
|                          | Other characteristics result from individuals’ interactions with the environment, which can range from diet to learning.                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                         |
|                          | Many characteristics involve both inheritance and environment. (3-LS3-2)                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                         |
| LS3.B Variation of       | Different organisms vary in how they look and function because they have different inherited information.                                                                                                                                                                                                                                                                                                 | **Grade 3.** Analyze and interpret data to provide evidence that plants and animals have traits inherited from parents and that variation of these traits exists in a group of similar organisms.  
[Clarification statement: Patterns are the similarities and differences in traits shared between offspring and their parents, or among siblings. Emphasis is on organisms other than humans.]  
[Assessment boundary: Assessment does not include genetic mechanisms of inheritance and prediction of traits. Assessment is limited to nonhuman examples.]                                                                                                                                                                                                 |
| traits                   | The environment also affects the traits that an organism develops.                                                                                                                                                                                                                                                                                                                                     | **Grade 3.** Use evidence to support the explanation that traits can be influenced by the environment.  
[Clarification statement: Examples of the environment affecting a trait could include normally tall plants grown with insufficient water are stunted; and a pet dog that is given too much food and too little exercise may become overweight.]                                                                                                                                                                                                 |
means these statements are assumed to be true universally about all living organisms. Additional questions might include:

- “Are there any exceptions?”
- “What type of exceptions might we predict?”

We might also note the conditionality of some of the statements made in this learning standard set such as, “Many characteristics of organisms are inherited from their parents. Other characteristics result from individuals’ interactions with the environment.” These types of conditional statements are unusual in the standards overall, so we might ask,

- “How do we determine which characteristics are inherited?”
- “How do we determine which characteristics are acquired from the environment?”
- “Also, are there characteristics that arise from a combination of these causes?”
- “Can characteristics arise from other mechanisms?”

In other words, these tools for thinking, as presented in the standards, can be used to help lead students to think about what they might be used for, but also to recognize the need for additional tools. These simple questions can be used to lead discussions and activities that create chains and webs of possible investigations. In Chapter 4, we provide a more detailed model for how to use this analysis for instructional design.

**Redefining Knowing**

Discontinuing the use of the word knowing to refer to the state of possessing facts and skills (i.e., knowledge) in our brains, however, is proving to be very difficult for us (the authors), given how pervasive these dominant meanings are in our lives and the fact that this is how we learned to define and use this word. The students we work with are in a similar position, but in our experience they have an advantage because they already tend to view knowledge as action. The dominant meaning of knowing, however, surrounds them and permeates their lives. To help students keep the dominant view problematic, we need to adopt the meaning of knowledge and knowing as action and consistently contrast it to the dominant meaning of knowledge. One way to do this might be by having students spend a few hours studying and discussing what we actually mean when we say we know something. What do students say when asked, “What does it mean to say we know something?” Do students, who study what they mean when they say they know something, learn to see it is shorthand for a range of processes and experiences? Sue explored these questions in a more formal research study, funded by the National Science Foundation conducted in 2009–2011 with Anna Stetsenko, Catherine Milne, Kara Naidoo, Ranyee Chiang, and Laura Paskell-Brown.

When we interviewed third- and fourth-grade students about knowledge, the students expressed a broad range of answers and ideas, which are summarized in Table 3.3.
CHAPTER 3

Table 3.3. A summary of third- and fourth-grade student responses to the interview question: “When people say they know something, what do you think they mean?” or “When you say you know something, what do you mean?”

<table>
<thead>
<tr>
<th>When people say, “I know” it means they …</th>
<th>Third-grade answers (N = 86)</th>
<th>Fourth-grade answers (N = 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are confident.</td>
<td>22% (19)</td>
<td>27% (11)^1</td>
</tr>
<tr>
<td>Are trustworthy.</td>
<td>27 (23)</td>
<td>15 (6)</td>
</tr>
<tr>
<td>Have experience.</td>
<td>6 (5)</td>
<td>10 (4)</td>
</tr>
<tr>
<td>Have it in their head/mind.</td>
<td>8 (7)</td>
<td>15 (6)</td>
</tr>
<tr>
<td>Can/must prove it.</td>
<td>8 (7)</td>
<td>7.5 (3)</td>
</tr>
<tr>
<td>Have understanding/comprehension.</td>
<td>7 (6)</td>
<td>5 (2)</td>
</tr>
<tr>
<td>Learned it from others.</td>
<td>8 (7)</td>
<td>10 (4)</td>
</tr>
<tr>
<td>Are earnest.</td>
<td>0</td>
<td>2.5 (1)</td>
</tr>
<tr>
<td>Are using a conversational tool.</td>
<td>0</td>
<td>5 (2)</td>
</tr>
<tr>
<td>Are the discoverers.</td>
<td>0</td>
<td>2.5 (1)</td>
</tr>
<tr>
<td>Have expertise.</td>
<td>1 (1)</td>
<td>0</td>
</tr>
<tr>
<td>Have talent.</td>
<td>2.3 (2)</td>
<td>0</td>
</tr>
<tr>
<td>Can make predictions.</td>
<td>1 (1)</td>
<td>0</td>
</tr>
<tr>
<td>Have checked the information.</td>
<td>2.3 (2)</td>
<td>0</td>
</tr>
<tr>
<td>Can transmit information.</td>
<td>1 (1)</td>
<td>0</td>
</tr>
<tr>
<td>Have awareness of other’s motives.</td>
<td>3.5 (3)</td>
<td>0</td>
</tr>
<tr>
<td>Can do something automatically.</td>
<td>1 (1)</td>
<td>0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>2.3 (2)</td>
<td>0</td>
</tr>
</tbody>
</table>

^1 Percentages were calculated by dividing the number of answers in each category by the total number of answers given by the group of participants

Many of the students suggested knowing reflects a state of mind (confidence), but most also suggested it means we can do something or have done something. For example, if we say we know something it means we can prove it, show it, explain it, make predictions, or do something automatically (i.e., unconsciously, without thinking). If we say we know something it might mean we have experienced, learned, or confirmed it.

This simple exercise of asking students what they think it means to know something (about 15 minutes of class time or 2 minutes per child in interviews) yielded a trove of terms, words, and ideas that could be incorporated into school-wide expectations for discourse in science (and everyday life). The power of knowledge and knowing is
in action and, based on these results, we think it reasonable to assume most children already have a sense of this meaning we all experience. Explicitly discussing what we mean when we say we know something, however, opens the door to exploring how what we learned or produced through our knowledge-actions are tools for acting (e.g., thinking or learning). In other words, knowledge-actions and tools for thinking are interdependent. Each is impossible without the other. Actions require tools for thinking and tools for thinking arise and are transmitted through action.

We can demonstrate this interdependence in many ways. For example, when students were asked a related question, “How did you come to know that about … ?”, the responses were “I saw … ” “I heard …” “I did this experiment …” “I read …” and “My aunt/mom/dad/sibling/teacher/counselor told me …” These are knowledge-actions we all use every day (including career scientists), and each one allows us to marshal tools for thinking necessary for problem-solving activities. We explore the instructional implications of this further in Chapter 5. Once we identify the actions we are making when we say know something, then we can use those specific action words and begin to replace our use of the terms know and knowing.

CONTRIBUTION

Now we come to the notion of contribution and one of the questions of this chapter: How does one contribute to scientific knowledge? In this section we try to convince you there are many more ways than you might think. Armed with our new conceptualization of scientific knowledge as an interdependent relationship between knowledge-acts and tools for thinking we can rethink what it means to contribute to scientific knowledge.

A traditional notion of contributing to scientific knowledge is the idea of an individual or research team adding to the stockpile of facts. We featured examples of this process in Table 3.1 and the accompanying briefs. In our revised model of knowledge, however, making a contribution to science takes on a radically different meaning and can be conceptualized as both the production of tools for thinking about how the world works (and why things are the way they are) and as knowledge-acts. In the next two sections we present a few examples of elementary school students and teachers making a variety of contributions to science from examples we have collected from reports of teaching and learning projects.

Contributions through Tool Production

If we view the cultural tools of science as tools for solving problems concerned with how the world works and why the world is the way it is, then anyone who produces such a tool has made a contribution to science. We have suggested tools
include information, explanations, facts, ideas, laws, concepts, theories, schema, rules, norms, social practices, skills, and algorithms, and that production of these tools reflects the type of contribution typical of what we think of when we describe making contributions to science or scientific knowledge. Can elementary school students and their teachers accomplish this (the short answer is, absolutely!) and, if so, how? You may or may not be surprised to know there are hundreds of examples of elementary school participants contributing to tool production through what are called citizen science or crowdsourcing projects. One compelling research finding from a study of the Sudden Oak Death (SOD) Blitz program concluded “amateurs equaled professionals in their ability” to perform the necessary fieldwork (Meentemeyer, Dorning, Vogler, Schmidt, & Garbelotto, 2015). In other words, not only can amateurs contribute their contributions were reliable. Although the Meentemeyer et al. study did not include elementary school students (it did include high school students and K-12 teachers) the authors concluded as long as citizen education and technical programming was effective, the data contributed by citizen participants was trustworthy. Cohn (2008) reported a similar finding by David Delaney who documented that “third graders were right [at identification] 80 percent of the time, an acceptable accuracy rate for most ecological studies” (p. 195). Not only have researchers shown K-12 teachers and school-aged children and youth capable of contributing through various projects (as we will see in more detail next), scientists are relying on them more and more for tool production because the work of these learner–scientists is considered reliable by career learner–scientists.

There is no single profile of a citizen science project. They vary in terms of who administers them, how long they last, whether they seek local or global participation, and the type of fieldwork and computing skills they require. They might be coordinated by individual career scientists (e.g., Dan Duran is an evolutionary biologist and entomologist in search of an Elderberry Longhorn Beetle [Duran, 2014]); career scientists working at research institutes (e.g., SETI, NASA, Cornell Ornithology Lab); or organizations founded to coordinate large-scale data collection or data analysis activities to be used by scientists (e.g., GLOBE.gov). Some projects are short term (e.g., Nerds for Nature sponsored a 1-year campaign to learn about the Mt. Diablo recovery after the Morgan Fire [Nerds for Nature, 2014]) and some are long term (e.g., the Cornell Ornithology Lab has a project running since 1966). Some projects seek local participation while others seek global participants. Wikipedia has an index of current and past citizen science projects around the world (Wikipedia contributors, 2014b). Scientific American also curates a large index of primarily U.S.-based projects (Scientific American, 2014), and recently Zooniverse (Lintott et al., 2013) and Scistarter (Cavalier et al., 2014) have begun providing indices and entry points for contributing to projects in a variety of fields. Participation in these projects usually takes one of three forms, which we review and provide examples of next.
1. Analyzing data that have already been collected.
2. Collecting and sharing new data using specific protocols.
3. Designing and conducting independent research programs and sharing the results with a specific community.

Analyzing data that have already been collected. One international story of contribution that captured our attention and inspired us to write a lesson plan for upper elementary school students came from an online crowdsourcing project called GalaxyZoo (Lintott, 2014).

There are billions of galaxies in the universe, and astronomers have many questions about the classification of galaxies in the universe (e.g., spiral, globular) and about various galaxy phenomena (e.g., colliding galaxies). One method they use to learn more about galaxies is analysis of photos created by Earth-based and Earth-orbiting telescopes. The problem for career astronomers is these telescopes generate an enormous number of photographs—too many for the investigators to analyze personally, and the process cannot be automated well. It turns out humans are much more reliable than computers at recognizing and classifying unknown patterns, which is what these scientists need to proceed with their research. To process the enormous numbers of images produced by telescopes in the Sloan Digital Sky Survey (Astrophysical Research Consortium [ARC], n.d.), astronomers set up an online training course to teach anyone interested (with computer and Internet access) how to identify the known types of galaxies and galaxy phenomena. After passing a short online course, participants are certified as zoogoers and can immediately start conducting data analysis as part of the research team. For each photo, scientists average the classifications performed by many zoogoers and as a result are fairly confident in the reliability of the cataloging of each galaxy in the photographs. By careful observation and examination not only are scientists learning more about galaxies and their behaviors, but unexpected objects or phenomena might also be found.

In mid-August 2007, Hanny van Arkel, a science teacher in the Netherlands, made an unexpected discovery. Van Arkel posted a forum entry after identifying a weird green object (“voorwerp” in her original Dutch) and asked what it might be (van Arkel, 2007). Initially astronomers determined (1) its location, (2) the type of electromagnetic radiation it is emitting, (3) whether it is common or rare, and (4) whether it is a known or novel occurrence. There were a couple of related hypotheses for the nature of the object. Chris Lintott (the principal investigator of GalaxyZoo) and colleagues proposed it might be a quasar light echo (Lintott et al., 2009). Michael Garrett and colleagues at the European VLBI Network proposed the light was coming from an interaction between an energetic jet from supermassive black hole and the gas around a nearby galaxy (Baldwin, 2010). As of 2012, it looked like it might be a quasar light echo, but there remain open questions.
(Keel et al., 2012). Without zoogoers like van Arkel, it may have been many years before scientists identified this mysterious object.

Collecting and sharing new data using specific protocols. Many citizen science projects recruit nonaccredited or citizen scientists of all ages to collect and share data using standardized protocols, checklists, and observation logs. The Cornell Ornithology Lab at Cornell University has sponsored several such projects including Project FeederWatch (Cornell Lab and Bird Studies Canada, 2014), which has been running since 1987 and cosponsored with Bird Studies Canada. According to the lab’s main website, the project has about 15,000 members across North America who count birds at their feeders. They’re called FeederWatchers and they have “contributed valuable data enabling scientists to monitor changes in the distribution and abundance of birds. Using FeederWatch data, scientists have studied the influence of nonnative species on native bird communities, examined the association between birds and habitats, and tracked unpredictable movements in winter bird populations” (Cornell Lab of Ornithology, 2014). The project website lists 26 publications that used data generated by FeederWatchers.

Conducting independent research programs and sharing the results with a specific community. Many citizen science projects invite scientists at all levels of experience and accreditation (including the nonaccredited) to not only collect and submit data, but to use the protocols and larger databases to conduct independent investigations. The GLOBE Project is particularly good at documenting independent projects conducted by students and their teachers. Hundreds of projects illustrate examples of students contributing through local, independent research projects based on GLOBE project research protocols and various online support systems (GLOBE Program, 2014). For example, the Crenshaw School has been monitoring the freshwater supply of a local U.S. Fish and Wildlife–designated habitat. The elementary school is located in a storm-prone coastal area on the Bolivar Peninsula in Texas, and they have been monitoring the quality of the freshwater supply to the habitat since before Hurricane Ike in 2008. They have documented a variety of changes to that supply over the years, and the community looks to them for advice on the status of the water supply and consults their recommendations for the protections needed to ensure its health (Crenshaw School, 2012).

* * *

Occasionally, elementary student contributions to tool production reach national or international news outlets. These stories are often about student–researcher partnerships that result in a research report published in a scientific journal with students, teachers, and career scientists as coauthors. These are not at the scale of the citizen science or crowdsourcing projects, but they still illustrate tool production by young people.
One study was conducted by students at Blackawton Primary School in Devon, England, with the assistance of R. Beau Lotto at University College London (co-founder of “I, Scientist”) (Blackawton Primary School [BPS] et al., 2011). In this study, a group of 25 8–10-year-old children explain how they discovered “bumblebees can use a combination of colour and spatial relationships in deciding which colour of flower to forage from. [They] also discovered that science is cool and fun because you get to do stuff that no one has ever done before” (BPS et al., 2011, p. 168). The article is unusual in several respects. First, the narrative of the publication is based on transcripts from discussions with elementary school students. Second, the study was conducted with a career scientist who views science as play. To this team, science is “the process of playing with rules that enables one to reveal previously unseen patterns of relationships that extend our collective understanding of nature and human nature” (BPS et al., 2011, p. 168). In our experience, using “play” to describe science is typically not well received among our career-scientist colleagues who argue such a definition (one we find delightful) belittles the discipline and does not capture the nature and complexity of their work. Third, the notes and acknowledgements at the end of the paper indicate publication may have been pursued not only to share the findings with the scientific community, but also to prove young people can produce new tools and contribute to science. The authors explain in these notes they were denied funding for the project by a granting agency, whose referees claimed, “young people cannot do real science” (BPS et al., 2011, p. 172). We have personally experienced the same feedback from grant review panels in the United States, and find this assertion very puzzling in light of the overwhelming evidence that makes it a wholly unscientific conclusion.

In another example, a full-fledged study was conducted by a team of scientists, but initiated based on the results of a school project by a sixth-grade student in Philadelphia. After Simon Kaschock-Marenda conducted a study of artificial sweeteners for a school project and discovered one of them (Truvia) served as a potent insecticide, his father (a career scientist) decided to extend his findings. Simon’s experiment was repeated by a team of scientists at Drexel University who confirmed his observations, and he was listed as a coauthor on the study, which was published in the online journal PLoS-One (Public Library of Science) (Baudier et al., 2014). One of the authors (the boy’s father) is quoted as saying, “I would never have studied it first without the initial inquisitiveness of a sixth grader” (Blaszczak-Boxe, 2014).

Compared to the numerous scientific reports generated in established citizen science projects, publications like these are rare, but the publications from groups like Blackawton and Kaskchock-Marenda and colleagues receive the lion’s share of press coverage. This unbalanced news coverage of these two types of publications might lead some to believe only outstanding students, at special schools, with teachers well connected to career scientists, are capable of making meaningful contributions. Together with the hundreds of citizen science reports and activities,
however, the evidence overwhelmingly favors the conclusion elementary school age children are capable of contributing to science through the production of new tools, and they often do. Of course, children benefit from adults who can mediate a variety of practices and information (remember, tools are a cultural inheritance passed from generation to generation), but these partnerships are highly effective and produce valuable contributions. No adult should take the untenable position children cannot contribute in these forms with appropriate mediation.

**Contributions through Knowledge-Acts**

If we view knowledge-acts as the act of using cultural tools of science for exploring, defining, and solving problems concerned with how the world works and why the world is the way it is, then anyone who engages in such a knowledge-act has the potential to contribute to science. We have suggested that scientific knowledge be conceptualized as mutually interdependent tools and processes. With this definition, there is a broad range of knowledge-acts to consider. Although some are familiar (observation, explanation, argumentation, prediction, interpretation), many are not what we usually consider to be acts that count as a contribution to science or scientific knowledge. In the remainder of this chapter we show how teachers and elementary school students might contribute to science through a variety of knowledge-acts. One common feature for knowledge-acts to be considered contributions to science is they include talk and communication outside student’s classroom communities. Sharing can occur between the classroom community and parents, other classes in the same school, other schools, or the community at large (local and/or global). The following types of knowledge acts are clearly contributions when they expand self-development as part of community development.

- Asking investigable questions and seeking answers.
- Appreciating tools for thinking created by scientists and/or teaching others to appreciate these tools.
- Talking science.
- Designing and promoting ethical practice.

*Asking investigable questions and seeking answers.* Positioning students as researchers is a dominant theme throughout this book. In every chapter we propose lines of inquiry (knowledge-acts) within the context of science that students can pursue and shape to learn more about development, knowledge, and transformation. As soon as students share and discuss various aspects of their progress on a particular inquiry with people outside their immediate inquiry group, we argue they are contributing to science because they are sharing their curiosity, problem-posing, and problem-solving actions and exploring these actions with others. Sheila Jelly (1985) wrote an essay on teaching and learning to ask investigable questions. We often share it with our teacher-colleagues. In it, she recommends the following
CONTRIBUTING TO SCIENCE

strategy for turning children’s unproductive (or not easily investigable) questions into investigable ones to promote purposeful inquiry with real materials.

1. Analyze the question.
2. Consider whether it can be turned to practical activity (with authentic or simulated materials).
3. Carry out a “variables scan” and identify productive questions.
4. Use questions to promote activity.

Imagine one of your students asks you, “Why do airplanes stay up?” To analyze the question means you consider it and ask yourself (1) why the child is asking the question—is she looking for attention, does she want a direct answer, is she actually puzzled and interested; (2) whether there is a simple answer to the question that could be found in a dictionary or reference book or whether the answer is complex and would benefit from some exploration and investigation; (3) whether you feel you know a satisfactory answer and whether you think you can make it accessible to the child; and (4) whether you have the equipment and/or supplies you think you need for students to conduct investigations. If you find the children are interested in an answer to the question, and it will help them in other areas of their science growth, then Jelly suggests it’s probably a good idea to take the “Let’s see what we can do to learn more about this problem” approach.

At the start you may not be quite sure how to answer the question, but then you might remember learning or reading about ideas such as, lift, drag and air pressure and something about the shape of the wings. Now is the perfect time to learn more with your students, and Jelly suggests you start with a “variables scan.” Based on a minimal familiarity with planes (they have similar shapes, an engine or power source, they need a runway or long surface to take off, and the wings have flaps that move up and down or side to side), you can establish the plane-in-the-air-system (which includes the plane, the air, and maybe even the takeoff surface) and do a variables scan. In other words, we ask questions about each part of the plane-in-the-air-system—about the shape of the plane, its engine, the air, and perhaps the ground. How many questions can we come up with about the shape of the plane that might be relevant to the original question, “Why do airplanes stay up?”

Shape

• How is an airplane different from a car, bus or train?
• How is an airplane similar to a car, bus, or train?
• What do all airplanes have in common?
• Does changing the shape of the wing change whether an airplane can stay in the air?
CHAPTER 3

Engine

- If a plane stops moving forward, does it stay in the air?
- What keeps a plane moving forward?

Interactions

- What happens when anything moves through the air? Where does the air go?
- What happens when a plane moves through the air? Where does the air go?
- How does a plane moving through the air compare to how a car, truck, bus, or train moves through the air?

All of these are investigable questions can engage students in their quest to understand how planes stay in the air. We need to help students find relevant print and/or digital media (e.g., books, websites, videos) and make appropriate equipment and supplies available for experimentation and investigation (e.g., paper, tape, scissors, or even balsa wood, motors, and batteries or solar cells for older students).

In another example, how might we address the iconic question, “Why is the sky blue?” using this method? We might start by responding with another question, “Is the sky always blue?” and an investigation, “Let’s observe the sky for a week at several times a day (including nighttime) and record the colors we see.” Depending on the time of day, the cloud cover, where we live, the amount of smog or moisture in the air, we’ll find the sky can be pink, purple, yellow, orange, blue, gray, brown, and black, among a range of other colors. After this, there are many new questions we might pursue with students such as, “What is the sky made of?” and “How does it compare to other objects that are blue, like paper, ink, or some of the light passing through a prism?” These questions can lead us to a variety of explorations of interactions between matter and light, which can support student learning about our perceptions of color.

When students ask questions they are contributing to science. The more we can stimulate questions about the world from students—whether they are critical questions (e.g., Why is this the status quo?) or exploratory questions (e.g., How does that work?)—and support their interests in learning about the world, the more likely we are to be able to support them in making contributions to self- and community development.

Appreciating tools for thinking created by scientists and/or teaching others to appreciate these tools. We argue we have initiated an important shift in thinking when we teach students information, explanations, facts, ideas, laws, concepts, theories, schema, rules, norms, social practices, skills, and algorithms are tools for thinking rather than a stockpile of knowledge. We have suggested when students and teachers start to view the body of knowledge as tools for thinking, learning, and knowing, they also start to ask who invented this tool, what was
invented to accomplish, how might this be useful for what I want to accomplish, and am I interested in inventing tools like this? As students and teachers share this conceptualization with others, they contribute to the process of helping others see they too can ask these questions, and find new ways to enter and participate in the understanding, use, and production of scientific tools.

*The role of talking science in being, learning, knowing, and transforming.* In Chapter 2, we argued that collaborative transformation practice is an alternative and more productive way to refer to the process of human development (which includes being and becoming). Collaborative transformation refers to the endless, interconnected, and dynamic process of being and becoming, knowing and learning, and transforming and changing oneself and one’s environment (Stetsenko, 2010). When students engage in knowing and learning science, they are becoming people who use the tools of thinking developed by generations of scientists. They also become part of the next generation to modify existing tools and create new ones. At the heart of this process are all the ways students transform themselves, and are transformed by and change their environment. Talking science (e.g., seeing and describing the world scientifically) with others is considered a contribution to science, because it keeps the language and culture of science alive and ensures its evolution. A language and culture actively used, studied and lived is not at risk of obsolescence or death.

As science teachers we often promote a variety of ways of talking science such as:

- Using claims and evidence for reasoning and problem-solving processes such as observation, argumentation, and explanation.
- Observing and describing the world and how it works.
- Keeping tools for thinking problematic.
- Analyzing decision-making processes of self and others.
- Considering the merits of alternative explanations.

In Chapter 2, we also presented a cautionary tale about learning to talk science in school. From a learner perspective, it can be difficult to untangle the norms of talking science and the norms of talking school (often referred to as “doing science” and “doing school” in those studies). As we saw through the work of Varelas and her colleagues, children conflate school behavioral norms with science talk norms, especially when their interactions with the teacher during science focus on behavior management than cultural norms of science. A culture of control and manipulation sounds like this to students: “Good scientists stay seated,” “Good scientists raise their hands and don’t call out”, but an epistemic culture sounds like this to students: “Scientists ask lots of questions,” “Scientists wonder ‘what if …’,” “Scientists work together to create explanations, but they also compete to be the first to explain.” As we mediate students’ practice talking science, it is important we help them separate school norms from science talk norms and we reduce our reliance on school norms for controlling what is acceptable in science discourse as much as possible.
Designing and promoting ethical practice. Another way to make contributions that we have not yet discussed is for students to initiate or participate in designing and promoting ethical practice toward humans and all living and nonliving things. For example, students can monitor their treatment of animals in their science classroom. How do they view the animals’ purpose(s): Do they see the animals as samples or tools to control, study, and use as they please, or do they see the animals as fellow beings? Do they believe animals have rights? What rights do they have? Do students honor those rights in their classrooms? Are students responsible for protecting those rights? What about the nonliving (or dead), natural objects in their classrooms (e.g., leaves, rocks, twigs, dead insects)? How do students view these objects and their responsibilities toward these objects? These questions of ethical practice in interaction with the natural world can be extended as desired. Students can initiate studies in their local communities about resource distribution (where does their water come from, where does their food come from, and how are these resources distributed) or about pollution (what are the major sources of pollution in their communities and how are these sources being monitored and eliminated or reduced). Students can initiate studies of how tools of science are misrepresented in marketing and advertising (e.g., food labels, toy marketing, clothing styles). Students can learn how people in their community use the tools from science to conduct cost–benefit or risk analyses in their daily lives, or how they combine tools from science with other tools, beliefs, habits, and practices to make decisions.

CONCLUSION
By revealing common myths about knowing and knowledge production in science, recasting knowledge as knowledge-acts and tools for thinking, and rethinking contribution we have attempted to provide new guidelines for mediating student learning in science. The way we typically represent contribution in science is as a very specific product—a new or revised tool for thinking—made by accredited career scientists. In this chapter, we argued this limited vision of contribution is detrimental to teaching and learning. It leads to sentiments such as, “I’m not good at science,” “He’s a real scientific thinker, but she struggles,” “I could never do what they do because they’re much smarter (dedicated or interested) than I am.” We used a model of contribution based on the idea of collaborative transformative practices to demonstrate that students and teachers make a significant contribution to science simply by studying and learning what we already know about the world. We have also shown there are hundreds of examples of teachers and students producing, reproducing, and revising tools for thinking in science. It is time to end another myth—the myth that contribution is not possible by these groups.
CHAPTER 4

REPRESENTING SCIENTIFIC PROBLEMS AND TOOLS FOR THINKING

What Kinds of Problems Do Scientists Work on? Do I Like to Work on the Problems of Science? Would I Like to Be a Scientist?

In the previous chapter, we explained our negative feelings toward treating knowledge as an object. Under that condition, knowing means having or possessing these objects in our brains, and the key goals of learning science become building memory. This means storing specific facts and instructions for performing specific skills in our brains for random access. The most common form of pedagogy used to achieve this goal is called transmission instruction or banking education, because the information to be memorized is held by the teacher and deposited in, or transmitted to, the student.

We argued shifting our definition of knowledge to knowledge-acts—that is, utilizing tools for thinking—opens the door for participating and contributing to science in countless ways. The works of the American philosopher and educator John Dewey, the Russian psychologist Lev Vygotsky, the Italian educator Maria Montessori, and the Brazilian educator Paulo Freire inspire this view. All proposed similar alternatives to traditional pedagogical forms, which were common in their day and are still common today (e.g., banking education and transmission pedagogy). Their solution was to engage students in what Freire called dialogic education or problem-posing activity, what Dewey referred to as experiential education, what Montessori referred to as scientific pedagogy, and what Vygotsky referred to as mediated problem solving. All of these educators understood, from their work and observations, the problems people face in their daily lives are what drive us to learn, adapt, and create tools, rules and schema, communities, and roles and responsibilities for solving them. One way to engage students to work on scientific problems is by learning how problems are defined and approached, and by exploring whether students are interested in working on similar problems. We like to introduce students to problems scientists actually study. Ultimately, we want students to learn a variety of tools for thinking about the world, but we know some tools are more difficult than others for learners to grasp and use.

Vygotsky (1986) elaborated on two kinds of tools for thinking—everyday or spontaneous tools for thinking and scientific tools for thinking—and he studied their interdependent relationship during learning activity:
One might say that the development of the child’s spontaneous concept proceeds upward, and the development of his scientific concepts downward, to a more elementary and concrete level. This is a consequence of the different ways in which the two kinds of concepts emerge. The inception of a spontaneous concept can usually be traced to a face-to-face meeting with a concrete situation, while a scientific concept involves from the first a “mediated” attitude toward its object. Though scientific and spontaneous concepts develop in reverse directions, the two processes are closely connected. The development of a spontaneous concept must have reached a certain level for the child to be able to absorb a related scientific concept. (Vygotsky, 1986, pp. 193–194)

In other words, Vygotsky posited the existence of two pathways of learning characterized partly by the tools for thinking they aim to create or reproduce: (1) *Personal everyday experience*—which is necessarily grounded in experience and, therefore, concrete—is typically the source of spontaneous tools for thinking. Such tools are easily visualized because we are there to witness them. For example, we can see the ball bouncing down the hill and describe what we see. (2) *Theoretical representations*, which are taught to us in words, are often based on someone else’s (or a collective’s) experience. Theoretical tools do not initially have the same reality or weight in one’s mind. They are tenuous and harder to accept as believable. For example, we cannot see a ball rolling forever when there is nothing to impede its progress.

According to Vygotsky, it is the task of the educator to make the theoretical concrete, which means coaxing learners to incorporate and assign the theoretical structure being taught just as much validity as an observation introduced directly by their own senses. How can we do that? As we discuss in this chapter, we do it by using a structured set of questions to allow the theory to be populated by real people and by using real experiences to make the theoretical tool as easy to accept and use as one’s own direct experience or everyday tool.

To ensure we can merge the theoretical (what Vygotsky called the “scientific”) with the spontaneous tools of everyday experience, we need to investigate the theoretical, the everyday, the historical, and the present anytime we prepare for teaching and learning a new topic (or even one familiar to us). To do this we begin by interrogating the texts and sources we are about to use, and try to identify the tools for thinking promoted by various sources (also discussed in Chapter 3). Moreover, we ask ourselves:

- How can I strengthen my knowledge of the tools related to this subject? Specifically, what do I know about the historical production of the tools, and the synthesis done in hindsight, to create the tools we have today?
- What resources do I need to access in order to learn more?
- How will I decide to trust the resources I find?
**TOPIC: ENERGY CONCEPT**

*Reviewing Science Learning Standards and Creating Maps for Developing a Problem Narrative*

Occasionally, we will meet new teachers or teacher candidates who ask why they need to learn how to plan instruction or evaluate instructional materials especially when they can just go online and download ready-made lesson plans with detailed instructions and recommended readings. Our answer is instructional planning and materials evaluation:

- Is a great way for us to learn the material we aim to teach.
- Yields ideas for how to recontextualize common expository materials (including lesson plans).
- Helps us to create entry points so students want (or are at least willing) to adopt the chosen problem.
• Helps us anticipate potential confusion or misunderstandings.
• Familiarizes us with the historical context.
• Provides the opportunity to devise ways students can learn to master the tools we are expected to teach.

Typically, we begin our instructional material development projects by consulting the learning standards we, or the teachers we work with, are required to use. We create graphic organizers such as webs and concept maps in an effort to see one or more possible big pictures for teaching and learning. The goal of this exercise is to (1) be efficient with teaching and learning time by finding cross-cutting themes, (2) identify the most important concepts to learn deeply, and (3) identify what might be subsumed under another topic. This part of our process is reminiscent of the advice provided by many instructional material developers, including Grant Wiggins and Jay McTighe, to establish learning goals and identify the essential questions that will be considered (Wiggins and McTighe, 2005). Beyond that, the model presented here is unique to our instructional planning and review process.

We chose the energy concept tool for our illustration because energy is one of the fundamental crosscutting concepts in science necessary for understanding and explaining many natural phenomena using scientific discourse. According to the physics educator John Jewitt (2008), “Energy is a critical concept that is used in analyzing physical phenomena and is often an essential starting point in physics problem solving. It is a global concept that appears throughout the physics curriculum in mechanics, thermodynamics, electromagnetism, and modern physics. Energy is also at the heart of descriptions of processes in biology, chemistry, astronomy, and geology” (p. 38). In other words, if science is a subject that interests a student, energy is a concept that will be important to understand no matter what field she decides to study in more depth. We also chose the energy concept tool because it is commonly oversimplified in books for elementary school children and it is often presented as a concept scientists understand well, when in many ways this tool is still being invented. As we showed in the last chapter, the existence of dark energy was just realized a few years ago and we don’t know much about that at all! Teaching the energy concept tool provides an opportunity to study a tool under active construction. This means we’ll really have to ask a lot of questions and emphasize the unknown. In the planning process we share here, we aimed to pose questions about energy that we might eventually be able to use to engage students. Ideally, the purpose of our process is to help us prepare students to appreciate the complexity of the phenomena and objects they will encounter in their investigations of the world and in their conversations with others as they become scientists.

**Learning Standards for an Energy Concept Tool**

Science teachers (especially those in schools or districts with low test scores) are instructed to ensure their students are “meeting the learning standards for science”
or that their instruction “aligns with the standards.” This is used as an indicator their students are receiving an adequate science education. Learning standards for science are criteria for measuring what students have learned in school science. They are also an arbitrary list of “disciplinary core ideas” generated by a small group of writers using an unpublished set of review criteria. Instructional material developers (individual educators, as well as for-profit, nonprofit, and federally funded groups) create elaborate tables to demonstrate how their materials meet or align with local, state, and/or national guidelines. They make this marketing effort to reassure teachers and administrators (including school curriculum committees and professional developers) the instructional materials presented are appropriate resources for science instruction and, if used as intended, should lead to gains in student learning. Simply using the materials, however, is unlikely to achieve this unless the teachers and students explicitly discuss the object–motive itself (the standard). In other words, blindly following the directions without an eye to the object–motive will leave students and teachers dazed and confused.

Once we have decided what concept (e.g., energy chain) or cross grade-level theme (e.g., energy) we are investigating for instructional planning, we typically start with what we are required to teach. At the time of this writing, the most recent learning standards available at a national level were the Next Generation Science Standards (NGSS; Achieve, Inc., 2013), and we (and most of our colleagues) will be expected to meet these standards in our instruction. Therefore, the NGSS for energy are our first stop in our planning process.

When we examined the learning progressions recommended in the NGSS for K–5 learning about the concept of energy, we found a bewildering stockpile of decontextualized facts, concepts, and laws that were not organized in a useful way (Achieve, Inc., 2013). They do not reflect the progression of authentic problem narratives or even a useful learning narrative. We began by assembling two summaries of the learning expectations across the grades in order to get a better idea of the major tools students were expected to learn and how these were related. The first summary we made was of the disciplinary core ideas (DCIs) presented in the NGSS standards for energy (Table 4.1), and the second summary we made presented these standards as organized in the recommended “learning progression” found in NGSS Appendix E (Table 4.2). We were familiar with the phrase learning progression, but had never searched for a definition. One definition of learning progression written for teachers is “a road or pathway that students travel as they progress toward mastery of the skills needed for career and college readiness. Each road follows a route composed of a collection of building blocks that are defined by the content standards for a subject” (Commonwealth of Pennsylvania, 2014). After examining the learning progressions presented in the NGSS, we would argue many are in need of modification and improvement, especially the energy concept tool.
Table 4.1. The “disciplinary core ideas (DCI)” and the performance expectations for students as presented in the NGSS standards related to the concept of energy in the physical sciences (Achieve Inc., 2013)

<table>
<thead>
<tr>
<th>Grade</th>
<th>DCI topic</th>
<th>Disciplinary Core Ideas (DCI)</th>
<th>Performance standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>PS3.B: Conservation of Energy and Energy Transfer</td>
<td>Sunlight warms Earth’s surface. (K-PS3-1), (K-PS3-2)</td>
<td>K-PS3-1. Make observations to determine the effect of sunlight on Earth’s surface. [Clarification statement: Examples of Earth’s surface could include sand, soil, rocks, and water] [Assessment boundary: Assessment of temperature is limited to relative measures such as warmer/cooler.]</td>
</tr>
<tr>
<td>1</td>
<td>PS4.A: Wave Properties</td>
<td>Sound can make matter vibrate, and vibrating matter can make sound. (1-PS4-1)</td>
<td>1-PS4-1. Plan and conduct investigations to provide evidence that vibrating materials can make sound and that sound can make materials vibrate. [Clarification statement: Examples of vibrating materials that make sound could include tuning forks and plucking a stretched string. Examples of how sound can make matter vibrate could include holding a piece of paper near a speaker making sound and holding an object near a vibrating tuning fork.]</td>
</tr>
<tr>
<td>1</td>
<td>PS4.B: Electromagnetic Radiation</td>
<td>Objects can be seen if light is available to illuminate them or if they give off their own light. (1-PS4-2)</td>
<td>1-PS4-2. Make observations to construct an evidence-based account that objects can be seen only when illuminated. [Clarification statement: Examples of observations could include those made in a completely dark room, a pinhole box, and a video of a cave explorer with a flashlight. Illumination could be from an external light source or by an object giving off its own light.]</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Some materials allow light to pass through them, others allow only some light through and others block all the light and create a dark shadow on any surface beyond them, where the light cannot reach. Mirrors can be used to redirect a light beam. [Boundary: The idea that light travels from place to place is developed through experiences with light sources, mirrors, and shadows, but no attempt is made to discuss the speed of light.] (1-PS4-3)</td>
<td>1-PS4-3. Plan and conduct an investigation to determine the effect of placing objects made with different materials in the path of a beam of light. [Clarification statement: Examples of materials could include those that are transparent (such as clear plastic), translucent (such as wax paper), opaque (such as cardboard), and reflective (such as a mirror).] [Assessment boundary: Assessment does not include the speed of light.]</td>
</tr>
<tr>
<td>-------</td>
<td>------------------------------</td>
<td>-----------------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>4</td>
<td>The faster a given object is moving, the more energy it possesses. (4-PS3-1)</td>
<td>Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced. (4-PS3-2), (4-PS3-3)</td>
<td>Light also transfers energy from place to place. (4-PS3-2)</td>
</tr>
</tbody>
</table>

| 4-PS3-1. Use evidence to construct an explanation relating the speed of an object to the energy of that object. [Assessment boundary: Assessment does not include quantitative measures of changes in the speed of an object or on any precise or quantitative definition of energy.] |
| 4-PS3-2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents. [Assessment boundary: Assessment does not include quantitative measurements of energy.] |
| 4-PS3-3. Ask questions and predict outcomes about the changes in energy that occur when objects collide. [Clarification statement: Emphasis is on the change in the energy due to the change in speed, not on the forces, as objects interact.] [Assessment boundary: Assessment does not include quantitative measurements of energy.] |
Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy. (4-PS3-2), (4-PS3-4)

4-PS4-3. Generate and compare multiple solutions that use patterns to transfer information. [Clarification statement: Examples of solutions could include drums sending coded information through sound waves, using a grid of 1s and 0s representing black and white to send information about a picture, and using Morse code to send text.]

When objects collide, the contact forces transfer energy so as to change the objects’ motions. (4-PS3-3)

The expression “produce energy” typically refers to the conversion of stored energy into a desired form for practical use. (4-PS3-4)

The energy released [from] food was once energy from the sun that was captured by plants in the chemical process that forms plant matter (from air and water). (5-PS3-1)

5-PS3-1. Use models to describe that energy in animals’ food (used for body repair, growth, motion, and to maintain body warmth) was once energy from the sun. [Clarification statement: Examples of models could include diagrams, and flowcharts.]

<table>
<thead>
<tr>
<th>Grade DCI topic</th>
<th>Disciplinary Core Ideas (DCI)</th>
<th>Performance standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy. (4-PS3-2), (4-PS3-4)</td>
<td>4-PS4-3. Generate and compare multiple solutions that use patterns to transfer information. [Clarification statement: Examples of solutions could include drums sending coded information through sound waves, using a grid of 1s and 0s representing black and white to send information about a picture, and using Morse code to send text.]</td>
</tr>
<tr>
<td>4 PS3.C: Relationship Between Energy and Forces</td>
<td>When objects collide, the contact forces transfer energy so as to change the objects’ motions. (4-PS3-3)</td>
<td>None listed.</td>
</tr>
<tr>
<td>4 PS3.D: Energy in Chemical Processes and Everyday Life</td>
<td>The expression “produce energy” typically refers to the conversion of stored energy into a desired form for practical use. (4-PS3-4)</td>
<td>None listed.</td>
</tr>
<tr>
<td>5 PS3.D: Energy in Chemical Processes and Everyday Life</td>
<td>The energy released [from] food was once energy from the sun that was captured by plants in the chemical process that forms plant matter (from air and water). (5-PS3-1)</td>
<td>5-PS3-1. Use models to describe that energy in animals’ food (used for body repair, growth, motion, and to maintain body warmth) was once energy from the sun. [Clarification statement: Examples of models could include diagrams, and flowcharts.]</td>
</tr>
</tbody>
</table>
### Table 4.2. The “disciplinary core ideas (DCI)” related to the concept of energy in the physical sciences presented in the intended learning progression from kindergarten through grade 5 (Achieve Inc., 2013)

<table>
<thead>
<tr>
<th>DCI topic</th>
<th>K–2 DCIs</th>
<th>3–5 DCBs</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS3.A Definitions of energy</td>
<td>N/A</td>
<td>Moving objects contain energy. The faster the object moves, the more energy it has. Energy can be moved from place to place by moving objects, or through sound, light, or electrical currents. Energy can be converted from one form to another form.</td>
</tr>
<tr>
<td>PS3.B Conservation of energy and energy transfer</td>
<td>Sunlight warms Earth’s surface.</td>
<td></td>
</tr>
<tr>
<td>PS3.C Relationship between energy and forces</td>
<td>Bigger pushes and pulls cause bigger changes in an object’s motion or shape.</td>
<td>When objects collide, contact forces transfer energy so as to change the objects’ motions.</td>
</tr>
<tr>
<td>PS3.D Energy in chemical processes and everyday life</td>
<td>Sunlight warms Earth’s surface.</td>
<td>Energy can be “produced,” “used,” or “released” by converting stored energy. Plants capture energy from sunlight, which can later be used as fuel or food.</td>
</tr>
<tr>
<td>PS4.A Wave properties</td>
<td>Sound can make matter vibrate, and vibrating matter can make sound.</td>
<td>Waves are regular patterns of motion, which can be made in water by disturbing the surface. Waves of the same type can differ in amplitude and wavelength. Waves can make objects move.</td>
</tr>
<tr>
<td>PS4.B Electromagnetic radiation</td>
<td>Objects can be seen only when light is available to illuminate them.</td>
<td>Object can be seen when light reflected from their surface enters our eyes.</td>
</tr>
</tbody>
</table>
With these summaries of the standards in hand, our initial questions were:

1. Why this content?
2. Why this organization?
3. Why these boundary rules?
4. What alternative organization(s) are applicable?
5. How can we recontextualize these concepts, ideas, and actions to ensure students see them as tools for thinking?
6. How can we rehumanize the production of these tools in our design of instructional planning to increase the likelihood students will learn about who produced these tools and what drove their work?
7. How can we promote children’s (and teachers’) interest in, and enthusiasm for, exploring the NGSS concepts related to energy?
8. How can we create a meaningful learning progression that will motivate children for further learning in grades 6–12, and beyond, in order to increase their chances at success?

We found it was difficult to answer the first three questions in any sort of detail—why this content, why this organization, and why these boundary rules—because there was no public record of the conversations and discussions by the committee that generated these current standards. We agreed that one obvious answer to these questions was that the selection, organization, and boundary rules reflected the decisions of the writing team assembled to write these standards. We wondered, who wrote these standards? According to the nexgenscience.org website, we found the writing team was composed of 41 members from 26 states with expertise in science, special education, language education, assessment, and workforce development. We were curious to learn more, so we summarized the professional position and educational background of each author listed on the nexgenscience.org website (see Appendix E). The NGSS document we consulted was a product of the work of a small group of individuals who reviewed input from public commentary and filtered it through their vision of science and engineering education to produce the version we considered. We felt it was important for our work to recognize that a version of the NGSS by another group of people selected by another set of criteria would likely have led to a different set of standards. In other words, we would not consider the NGSS a sacred text.

Next, we addressed the fourth question on our list: What alternative organization(s) of physical science concepts is applicable? To help us answer this we decided to create an alternative graphic representation of the DCI topics listed—a web to view the relationships between the various concepts presented in the K–5 learning progression for energy in the physical sciences (Figure 4.1).

This graphic organizer illustrated for us the lack of connection we suspected between the DCI topics. It provided us with little more than keywords for learning more about each topic. We noted nearly any curriculum could be aligned to this set
of topics if it claimed to present students with explanations of these key ideas and/or to provide demonstration activities teachers could use to help students discover the meaning of these ideas through hands-on experiences. This meant we would need to take extra care with any prepackaged curriculum that claimed to meet these standards. It also meant that our planning process was necessary and valuable to improve the presentation of content, flow, and relationships to be taught, in order to ensure meaningful learning experiences for our students.

Because the NGSS also provided a learning progression for the concepts under the energy topic in the physical sciences, we decided to create an alternative graphic representation of this progression to see whether that clarified the content, flow, and relationships to be taught (Figure 4.2). In this diagram we arranged the DCI topics, over time as proposed by the standards, using a graphic modeled after those presented in the *Atlas of Scientific Literacy* by the American Association for the Advancement of Science (AAAS) (AAAS and Project 2061, 2001). The AAAS format is referred to as a “conceptual strand map” and is intended to show how students’ understanding of the idea and skills that lead to literacy in science might develop from kindergarten through 12th grade. In this case, our map showed how the NGSS writing team believed students should develop from kindergarten through fifth grade, and it also included the expectations for student performance.
Figure 4.2. Conceptual strand map of the learning standards for energy presented in the Next Generation Science Standards (Achieve, Inc., 2013)
Figure 4.2. (Continued)
As we reviewed this map, we realized the learning progression provided in the NGSS did not provide any guidance on how to make the conceptual strand map more integrated or robust. For example, the definition of energy, which should be developed in the grade 3–5 span, is related to the five major ideas presented under the energy concept. However, only one K–2 learning goal is highlighted by the standards as sufficient to serve as a foundation for the definition of energy expected in grades 3–5—the fact that “sunlight warms Earth’s surface.” Surely, we thought, making this observation alone will not be enough to lead students in the development of the definition of energy provided in the document.

Based on this conceptual strand map, we also looked more closely at the definition of energy provided in the standards. What we found was surprising. The definition listed was not a definition at all; it was a description of energy. It contained only a list of facts, statements, and assertions about energy. This led us to ask, “What is the definition of energy?” We compared energy definitions from a variety of sources to the description of energy labeled as a definition provided by the NGSS (Achieve, Inc., 2013). Our analysis is shown on Table 4.3.

Before you continue reading, take a moment to consider the definitions of energy provided on Table 4.3 and compare them to the description of energy provided by the NGSS. Do you see why we claimed the NGSS text is a description of energy and not a definition of energy? What do the definitions on Table 4.3 have in common? Which definitions provide you with a perspective or wording you find understandable? Which do you find confusing or unintelligible? What questions about energy do you have after reading these definitions? When you consider the map shown in Figure 4.2 in light of these definitions on Table 4.3, what questions about teaching and learning arise?

The following thoughts and questions about the problem of teaching and learning the energy concept tool occurred to us from our perspective as a teacher imagining what it might be like to be a young student considering the definitions for energy provided by various sources:

• If energy is the “property” of a system, then that implies all systems can be described in terms of this property (energy). Is this what is meant by property? Why is there no mention of systems or property in the NGSS DCIs? How come the only time property is mentioned in the K–5 NGSS is under the heading “wave properties”? What is a wave property, and what does that have to do with energy? Do all forms of energy have this wave property, or only some forms? How does this help us understand the energy concept tool?

• If energy is the ability or capacity to do “work,” then why is work never mentioned explicitly in the K–5 standards? Are the K–5 concepts under the heading “Relationship between energy and forces” supposed to represent work concepts? A closer look at the grade 3 standards (forces and interactions) and the grade 4 standards (energy) does not reveal any exploration of the work concept. Is work a helpful concept to introduce in a study of energy concepts? Will it help students learn some of the other DCIs required for this grade range?
Table 4.3. Definitions of energy

<table>
<thead>
<tr>
<th>Definition</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving objects contain energy. The faster the object moves, the more energy it has. Energy can be moved from place to place by moving objects, or through sound, light, or electrical currents. Energy can be converted from one form to another form. <em>(This is a description not a definition of energy)</em></td>
<td>Achieve, Inc. (2013)</td>
</tr>
<tr>
<td>Energy is the capability of causing a transformation or change in the condition of matter, most commonly by work or heat. Doing work on an object, for example, increases its energy. The energy of a system can be used to do work on other systems.</td>
<td>Griffith (2001) p. 458</td>
</tr>
<tr>
<td>A body has energy either if it is already in a state of motion, or if, even though at rest, it can through appropriate means put itself or another body into a state of motion.</td>
<td>Chandrasekhar (1998) p. 38</td>
</tr>
<tr>
<td>Energy is the ability to do work. Energy can take a number of forms and can be converted from one form to another.</td>
<td>(FOSS Web, 2008)</td>
</tr>
<tr>
<td>Energy is the capacity for doing work. You must have energy to accomplish work – it is like the “currency” for performing work. To do 100 joules of work, you must expend 100 joules of energy.</td>
<td>(Nave, 2012)</td>
</tr>
<tr>
<td>Energy is the capacity of a physical system to perform work. Energy exists in several forms such as heat, kinetic or mechanical energy, light, potential energy, electrical, or other forms.</td>
<td>(Jones, n.d.)</td>
</tr>
<tr>
<td>Energy is a property used to describe a wide variety of things from the tiniest particles to the most complex systems. But unlike physical properties such as color, length or temperature its better understood by what it can do than by how it looks or feels. The standard definition of energy is the ability to do work. In other words, it’s the ability to create some sort of change in an object whether it’s the object’s location or the motion of its atoms.</td>
<td>(NOVA Labs, Aguirre, &amp; Neal, (n.d.))</td>
</tr>
<tr>
<td>Energy is the capacity to do work. When we do work on an otherwise isolated system its capacity to do work is increased, and so its energy has been increased. When the system does work its energy is reduced because it is then capable of doing less work than before.</td>
<td>Atkins (1986) p. 39</td>
</tr>
</tbody>
</table>

*Although we included a definition from About.com, when looking to online sources we tend to avoid “.com” websites and opt for sites developed by or in collaboration with career scientists and science educators, which are usually well known .org or .edu sites or sites recommended by NSTA, AAAS. This is our practice because authorship is typically clearly stated in non-commercial sources.*
CHAPTER 4

- Is it fair to describe the energy property as “capacity” or “ability”? In other words, can we measure the capacity or ability like we can measure parameters such as color, length, density, or phase of matter? If so, how do we measure capacity or ability to do work or cause a change? Can we measure the energy of an object, or can we only measure the energy of a system? What is considered an object and what is considered a system?

- Teachers often use analogies to visualize and communicate invisible phenomena, concepts, or ideas to students. How useful is the analogy of energy as currency for teaching the concept of energy to children? Can this analogy be used with younger students without creating confusion? Are there alternative analogies that might be more useful?

Although we agreed the core ideas covered in the NGSS were relevant to the energy concept tool, we now had some major concerns with the organization and selection of these ideas based on our initial review of the standards. At that point, we decided it was a good time to investigate the concept of energy further.

When we decide to investigate a tool for thinking like energy we typically begin by determining the who, what, where, when, and how of the tool’s origins and utility (Figure 4.3). We take this approach because it provides just the right amount of structure we feel we need to organize and make sense of the mountains of information we often encounter during our Internet searches and library research. We’ve also found it works for studying any kind of tool for thinking.

Figure 4.3. Transforming the Next Generation Science Standards DCI topic, energy, into a graphic organizer to guide problem narrative production

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• Who invented the concept of energy? Who uses the concept of energy in problem solving today?
• The concept of energy is a tool for thinking, but what is energy? (i.e., what is the definition of energy?) What problems did/does the concept of energy help to solve? What remains unclear about the concept of energy? What interests me about the energy concept?
• Where can we learn more about the energy concept? Where did the inventor(s) of the concept of energy come from?
• When was the concept of energy invented?
• How do we study energy? How do we contribute to a deeper understanding of energy? How is understanding energy useful in my/our lives?
• With the benefit of hindsight, what new tools were created for learning what is already known about energy?

Before we illustrate how we answered these questions, we want to say a few words about this organizer. The graphic organizer shown in Figure 4.3 was developed for instructional planning purposes. Recently, we realized it might be a useful organizer for students’ learning actions. In its generic format, students can use it to track the tool information as they learn it. This organizer could be used as a long-term reference for students to use (and expand) over the course of years. It can be stored electronically as part of student’s learning portfolios or as paper copies in student science journals, binders or folders. A blank for reproduction purposes can be found in Appendix F. Of course, the format (a web) is not critical, but the questions are.

*What Is Energy?*

We decided to continue with our hunt for a clear definition of energy—if one was to be had. We began with a close reading of the definitions on Table 4.3 and decided energy is not a physical object, even though it is a real natural phenomenon. It is described as a property, but it is not a physical property. It is also described as analogous to money, but it is not a physical object like a coin or a bill. It is a capacity or ability to do work or cause a change, but it is not the work or change itself. Energy can even be expressed mathematically; therefore, it can be measured. For example, if you have a lot of energy (a measurable quantity) then you can do a lot of work (a measurable quantity). Energy appears to be something real that makes change possible, but it is also an idea of something real. In other words, energy is a theoretical construct that helps us to explain how change is or is not possible. Based on these definitions, we asked a few questions:

• If energy is the ability to create a change (e.g., “do work”), then how does an object (matter) possess the ability to create a change or do work (i.e., how is the ability to do work stored)?
If energy is the ability to do work then what happens to that ability when work is done on an object by that ability? Is the ability ever exhausted or is the ability an infinite resource?

If the ability to do work is not an infinite resource, then where does it go and where does it come from?

Not surprisingly, our search for a definition led to more questions, which is really what makes the whole process enjoyable for us. Now that we were a bit more confident about the subtlety of the energy definition, we felt we had a clearer conceptual lens through which to look as we continued our inquiry. We decided to shift our attention to figuring out who invented the concept of energy and why.

Who Invented the Concept of Energy and Why Was the Concept of Energy Invented?

We started our Internet media investigation for answers to these questions with Wikipedia. Really. The reason we often start with Wikipedia at the beginning of a project is because it typically provides a fairly reliable introduction to uncontroversial scientific topics. The history section provides a summary of a communal belief about appropriate attribution and specific names, all of which can be fact-checked and then accepted, disputed, and/or refuted. Like all sources we consult, we hold information gingerly and keep asking questions. According to the Wikipedia entry on energy (June 2014), the modern meaning of the ancient word energy was invented by Thomas Young, which he used in a lecture to the Royal Society (London) in 1802 to describe the relationship (incorrectly) between a mass and its motion (energy = mass × velocity² or E = mv²) (Wikipedia contributors, 2014a). We checked this claim in a few texts we had gathered at the beginning of the project based on a library catalog search.

According to the science historian Jennifer Coopersmith (2010), who wrote Energy, the Subtle Concept, Thomas Young was “the first to use the word [energy] in physics since Johann Bernoulli had used it for his concept of virtual work in 1717” (Coopersmith, 2010, p. 176). Coopersmith explained that Young used it to refer to what we now call mechanical energy, or kinetic energy, and “while the meaning of the term didn’t exactly coincide with our modern meaning, the increasing use of the word ‘energy’ [introduced by Young] indicated that a new entity was soon to enter the physical stage” (Coopersmith, 2010, p. 176). Isaac Asimov (1966) also credited Young with the introduction of a new meaning for the preexisting word energy and explained that the word gradually became popular after Young’s use was published in 1807 (Asimov, 1966). We were satisfied the word was popularized after its most recent introduction, but understood that its meaning would change over time as we traced its history and development. Young, however, was not the person to introduce the relationship E = mv². We learned from Coopersmith that Gottfried Liebniz described this relationship, except he called it vis viva, or “living force,” at
the time. It was Young who proposed replacing *vis viva* with “energy.” Why he saw
the need for such a replacement we’ll get to shortly.

For an answer to this question, and others to come, we knew we needed to rely on
some historians of science, so we assembled the following texts based on our library
catalog search:

- Jennifer Coopersmith (2010). *Energy, the Subtle Concept*.

Among these, only Asimov really wrote for the general public. The books by
Coopersmith and Simonyi are quite dense and intimidating for the casual reader. This
is where our organizer (*Figure 4.3*) came in handy. By focusing on a single question,
we utilized the indices and tables of contents to home in on particular pages and/or
passages we could supplement with other resources found online. Initially, we also
consulted a few college physics textbooks, but these usually glossed the history so
much we eventually decided they were not useful. The online sources we found most
useful included:

- *The Physics Hypertextbook* by Glenn Elert, a high school teacher at Midwood
  High School at Brooklyn College: [http://physics.info](http://physics.info)
- *Hyperphysics* by Carl R. Nave, a professor in the Department of Physics and
  Astronomy at Georgia State University: [http://hyperphysics.phy-astr.gsu.edu/
hbase/hph.html](http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html)
- A collection of articles by John Jewett, Jr. published in *The Physics Teacher*:
  “Energy and the confused student.”

Simonyi’s story of energy begins with efforts to answer philosophical questions
about existence, constancy, and change. Pursuing answers to questions such as
“What is the world made of?”, “What is the fundamental principle that holds the
world together?”, and “What is the fundamental principle of all existence?” were
foundational to our collective understanding of energy. According to Simonyi, the
Greek philosopher Democritus (460–370 BCE) provided one of the best answers
to explain how change was possible in a context of permanence (i.e., the constancy
in change problem) with his atomic theory. Democritus’ theory was, “The world
consists only of atoms, whose substance is completely homogeneous, and the space
between them. The diversity of the world is the result of the various connections
between the atoms and of their motions. The atoms themselves differ in their
forms, sizes, positions, and velocities” (Simonyi, 2012, p. 61). In other words,
the universe is made of a limited number of fundamental building blocks (atoms)
and the space between them. Democritus argued the extraordinary variety of what
we see in the world, such as rocks, plants, people, and animals, is due to the vast
number of ways these building blocks could be assembled and arranged. A common
analogy to describe this theory is language. Think of the vast number of words and
possible meanings we can generate using only 26 letters of the alphabet—we can
keep inventing new words and meanings for a very long time without any threat of running out. Now imagine if there were only 26 elements in the world (there are least 118 to date); each “word” built from a combination of those elements would be a distinct object. According to Democritus, the consequences of such a theory (which is not much different than our present-day atomic theory) were numerous and included the statements that:

- Everything is made of a limited number of atoms.
- Nothing arises from nothing.
- Nothing can be destroyed to become nothing.

These statements roughly comprised the modern definition of conservation, which means nothing is created or destroyed. We learned from Simonyi that although physicists have expanded, refined, and revised Democritus’ statements, his central idea of conservation is found in the physical laws on which we rely and teach today. For instance, the 18th-century chemist Antoine Lavoisier is credited with demonstrating and extending the idea nothing arises from nothing to develop the law of the conservation of mass and the closely related concept of the conservation of matter (e.g., matter cannot be created or destroyed, only changed from one form into another). Based on the more recent work of Albert Einstein, contemporary nuclear and astrophysics now couple the conservation of mass with the conservation of energy to ensure the total mass energy of the universe is conserved. This, however, is beyond the scope of the purpose of this discussion (interested readers might consult Lasky, 2007). For now, let’s get back to the early story of energy.

We understood Democritus’ conservation principle was very attractive to early philosophers because it could address big questions such as: What is the world made of and how is it assembled in all of its variety? But we still weren’t sure what that had to do with energy. Here is where we found Isaac Asimov’s story of energy very useful. According to Asimov, the conservation principle was considered so useful that it was applied freely to explain a variety of life experiences, including work. But it eventually became clear it couldn’t be used to understand work.

To say work must be conserved seemed an appropriate application of the conservation principle because work cannot be done magically; it has to come from somewhere and be done by something on something else. We all know from experience we have to do something to an object in order to accomplish work. There was a problem with the conservation of work idea, however, because work does seem to disappear. For example, when a book falls from our desk, work is done on the book by the force applied by our hand because the book moved a distance from the desk to the floor and its position was changed. Where did the work go after this event? Is it still in the book? Is it transferred to the floor? Is it in the table? Is it in the air? Is it in the gravitational field in which we live? Is it back in our hand? It seems to have disappeared. Also, the book moved because we pushed it—we did the work on the book. Where does the work of our moving arm come from?
To 17th century scientists, the work done by our moving arm seemed to appear out of nowhere. According to Isaac Asimov, Gottfried Leibnitz (1646–1716) proposed humans can store work and he called this work-store *vis viva*, or “living force.” The problem with this idea was nonliving things could do and store work, too. For example, wind filled the sails of a ship and drove it forward through the water. Waterfalls turned waterwheels and the mill stones used to grind grain into flour. It was clear from these everyday observations work must also be stored in nonliving things. This is why Young felt the need for a replacement word. “Thomas Young (1773–1829) developed a neutral term to replace *vis viva* that could be applied to any object. He called the work-store ‘energy’ from the Greek meaning ‘work-within’” (Asimov, 1966, p. 94).

Armed with the idea of energy as the ability to do work (or store work), people could explore various phenomena to describe the types of energy or work-within. We know the end of the story—energy is conserved not work—but these natural philosophers and engineers didn’t understand this yet, so many continued to focus their efforts on the puzzle of how work was conserved, not how energy was conserved. According to Coopersmith, Daniel Bernoulli (1700–1782), however, proposed *vis viva* was the conserved element (not-work), and it was conserved not only in a variety of mechanical settings, but also in swirling steam, an expanding gas, a lump of coal, a metallic spring, and gunpowder. In other words, Bernoulli not only recognized energy was conserved he recognized it was found in everything and was a source of fuel or power. Bernoulli was ahead of his time, and it would still be quite a while before his modern-day concept of energy was recognized. This is what makes the invention of the energy concept tool, as we were learning it, a long and complicated story (like most problem narratives in science!). As natural philosophers, hobbyists, and engineers attempted to track where work came from and where it went, some began to track this “work-within,” “work-store,” “energy,” and describe its storage forms, how it was transformed, and how it was transferred between objects. At this point in our research, we were starting to see some familiar terms and a look back at Figures 4.1 and 4.2 showed these were all tools highlighted in the NGSS set for the K–5 DCI Energy. We felt we were on the right track in our energy research project.

With this idea of energy (work-store), the question of where work came from eventually morphed into how is energy stored, whether it is in living things, in wind, in water, or in books? According to Asimov, motion was probably the first form of energy storage to be recognized, even though Coopersmith suggests Bernoulli recognized most energy storage forms at the same time he studied motion. His ideas were only published posthumously, and he did not promote them when he was alive. Work involved motion, so it was not surprising moving objects could do work. As mentioned above, moving air (wind), not still air, drives sailboats; moving water, not still water, turns a millstone. It is not air or water per se that store energy, it is *moving air* and *moving water* that store energy. It was decided that anything moving
contained energy (or the ability to do work). “Lord Kelvin (1824–1907) introduced the term ‘kinetic’ from the Greek meaning ‘motion’ to describe energy associated with motion (kinetic energy)” (Asimov, 1966, p. 94) in approximately 1849–1851, but it was Gaspard-Gustave Coriolis who first outlined the mathematics of kinetic energy in a paper published in 1829 (Wikipedia contributors, 2014a).

We learned from Asimov that Kelvin’s definition of kinetic energy, however, was inadequate to develop a conservation law for work. The reason could be found in a very simple everyday event: throwing a ball straight up into the air. When we (or machines) throw a ball into the air, Kelvin would tell us it has a certain amount of kinetic energy. As we watch the ball climb upward, away from us (and the Earth), we can see it slow down—its kinetic energy seems to be disappearing. At some point the ball comes to a stop before falling back to the Earth. At that moment, it cannot have any kinetic energy because it is not moving, therefore that energy must be gone. If we believe in conservation of work, then that kinetic energy couldn’t have disappeared. So what happened to the energy when the ball reached the top of the arc and stopped moving?

To solve this problem, William Rankine (1820–1872) is credited with suggesting the kinetic energy of the rising ball is not lost, but it is stored in another form. Since work must be done against gravity to lift the ball to a particular height, then Rankin proposed that this work, done on the ball by the hand or machine, must be stored “in the form of energy that it contains by virtue of its position with respect to the gravitational field” (Asimov, 1966, p. 96). In other words, he argued this “energy of position” has the “potential to be kinetic energy so it should be called “potential energy” (Asimov, 1966, p. 96).

Now we were starting to understand how identifying these two forms of work storage, kinetic and potential energy, proved to be useful for describing the ability of an object (or system of objects) to do and store work. Understanding these forms meant work storage could finally be measured and tracked. Engineers and natural philosophers could calculate the velocity of moving objects to describe their kinetic energy and could measure the relative position of resting objects to describe their potential energy. We learned when they made these calculations for events like the thrown ball example, and added up all the work storage measurements, there were still losses of energy to be explained. Asimov explained it was obvious any object thrown into the air with a certain kinetic energy never returned to the ground with quite the same amount of kinetic energy. These investigators also knew when an elastic ball was thrown into the air and allowed to bounce, it never returned to its original height, but always bounced to a position lower than the previous bounce. If a ball of clay was thrown and dropped it struck the ground with a splat and the kinetic energy was gone with no re-formation of potential energy. It looked like kinetic energy was disappearing, and this was in violation of the conservation law of work people were trying to establish.

At this point, we wanted to learn a bit more about the story of the conservation of work and its demise or its reformulation as the conservation of energy, but when
we looked for resources describing this story we weren’t successful. As we returned
to Asimov, Coopersmith, and Simonyi, it became clear the story of energy was not
a single story but a collection of parallel and meandering stories—a bit like a pile
of spaghetti! For instance, a subset of the stories that fed into the production of
the conservation of energy concept were created in the 18th century and included
experiments that led to caloric theory of heat, the abstract theory of machines, and
the kinetic theory of heat, as well as the creation of the steam engine. In general,
Coopersmith and Simonyi had captured the multiple stories of energy better than
Asimov, but Asimov’s tendency to select a single story was far more manageable.
This, we realized, was probably the reason his writings about the history of the energy
concept were so much more accessible to newcomers. At that point, we recognized
some could accuse us of creating a single story in this chapter—something we find we
often do as science teachers. Teaching a single story is a manageable way to mediate
our students’ learning process, but this approach has its dangers, the most prominent
of which is the inadvertent creation of a story considered final or official, which
is then taught as the right or correct story. For our purposes, we decided to follow
the thread Asimov created (rejecting the conservation of work for the conservation
of energy), but we made a point to note that, in real time, the energy concept
tool was evolving in many fields concomitantly with contributions by engineers,
physicists, philosophers, mathematicians, chemists and myriad others interested in
forces, motion, heat, light, engines, efficiency, and work among other phenomena.
This complex of multiple stories makes more sense today because researchers have
since learned energy and matter interact with each other in subtle ways but in the
17th, 18th, and 19th centuries this was still unknown. In our atomic age, we have
even found matter and energy can be interconverted according to Einstein’s famous
formulation, finally explaining the source of the sun’s energy, but we’ll leave this
exploration for another time (Figure 4.4 notes a, b).

Let’s get back to the puzzle of the thrown ball and the disappearing kinetic
energy. Asimov suggested someone argued the losses of kinetic energy observed
in the thrown ball example were due to complications of working in the everyday
environment (we didn’t find who argued this, but it is possible someone did). If there
were a frictionless system, in a perfect vacuum, and all objects were completely
elastic, then energy would be conserved in the simplest interaction (between the ball
and the hand or machine). Although this was true, Asimov reminded us that a law of
conservation must function in the messiness of reality, which includes things like air
and gravitational fields, not only under ideal conditions. This meant someone had
to figure out what was gained for every loss of kinetic or potential energy and by
what. We remembered from our basic introduction to physics courses in college, and
even from some of the books for children about energy, any conservation law needs
to account for all the losses and gains within a system. We wondered, who invented
the idea of a system?

With such a universal term, system, we had no idea where to begin. So we searched
Wikipedia for system, and in the history section of the entry we were surprised to
Figure 4.4. Notes made while developing our understanding of the energy concept
find the concept of system as we use it today was probably first introduced Nicholas Léonard Sadi Carnot in the 19th century as a way to understand work done by engines. In other words, it wasn’t invented at the time potential and kinetic energy concepts were realized, but possibly much later (although Galileo also introduced it in his work it wasn’t widespread). We found this amazing and appreciated how challenging it was to explain the simple ball in the air problem without a notion of a system.

In the thrown ball case, we have learned we can define the system as: the ball, the gravitational field, the Earth, and the air (we’ll ignore the hand or machine that started the ball moving for now since that can be considered part of another system), but that wasn’t so trivial in the 19th century. It appears some energy is lost (the work stored has decreased) and we have to track it down, but without the benefit of a systems notion, it would not be obvious to do this. In hindsight it’s easy to wonder whether perhaps it was turned into yet another form, but this would not have been obvious at the time. At that point in our research, we were are still not sure how this all came together (historically), but we let that question rest (Figure 4.4 note c) because we were eager to learn more about the idea of energy transformation and energy transfer, which were big teaching topics we were required to cover.

We knew from children’s books and textbooks some of the energy of the ball system was transformed into yet another form different from kinetic and potential energy—heat due to friction. What we didn’t know was who figured that out. To answer that question we looked in our three main reference texts for this project and discovered Simonyi’s account of heat and energy wasn’t too difficult to follow. According to Simonyi, “progress in knowledge about the nature of heat was closely related to the development of the concept of energy” (2012, p. 365). He confirmed what we thought, the disappearance of kinetic energy, apparent in the tossed ball example (either loss from friction on the ball in the air or loss during a collision), was a very confusing fact. We learned expected connections were not made by natural philosophers at that time, and it was some time before they accepted heat and kinetic energy as two forms of energy. One of the main reasons was because the kinetic theory of heat (heat is the motion of the particles that make up an object) was temporarily abandoned and a substance theory of heat (and then the caloric theory) was adopted, but that’s yet another story in which the caloric theory was used to invent and explain the internal combustion engine. Remember one of the main points we are trying to make in this chapter is to appreciate the multiple stories of science. As we create a short story out of multiple, interwoven, long stories we hope readers will continue to question what we included and what we left out. Another point is many theories, which we now discard and understand to be flawed, were taken to be reasonable and instructional at the time; they framed the way scientists designed experiments, interpreted their observations, and planned next steps. Just as any theory does today. Teaching and learning how to look for multiple stories and how to recognize the various theories operating in a particular historical context can be exciting for scientist–learners.
Count Benjamin Rumford (1753–1814) conducted what is often touted in textbooks as one of the classic experiments that provided an explanation for the loss of kinetic energy due to complicated environmental conditions. Rumford was not particularly interested in establishing a conservation of work law when he conducted those experiments, but he did subscribe to the idea of conservation. In fact, he stated in a report “it was by accident that I was led to make the experiments of which I am about to give an account” (Rumford, 1798, p. 80), but according to Simonyi he was well aware of the debates among investigators about the nature of heat, and he believed heat was a form of motion. According to Coopersmith, Rumford was the director of a military arsenal in Munich at the time of this experiment, and he noticed the cannons acquired “a very considerable degree of heat” during the process of boring them in the workshops. This heat appeared to be created from nothing because there were no flames applied during the boring process; there was just a horse driving the cannon borer into the cannon being manufactured. So where did the heat come from?

We were able to track down Rumford’s original papers on the topic (with an Internet search using the reference provided by Simonyi) and were delighted to find them well written and easy to understand. We learned from Simonyi, Rumford, and Coopersmith that Count Rumford thought if he could understand the nature of this heat (especially where it came from) he could answer a long-standing philosophical question: What is heat? And he could settle one of the debates of his time: Is heat a form of motion (kinetic theory of heat), or is heat an object (substance theory of heat)? Rumford made several observations and conducted a few experiments (which were described well in his original reports), but until he conducted the following experiment he was not confident the friction of the borer piston grinding away the metal to form the cannon chamber was producing the heat.

He had a box built to fit around the cannon and the cannon borer portion of the machine. They filled the box with about “2.25 wine gallons” of water, which was kept excluded from the inside of the cannon being bored. Then they “put the machine in motion” (i.e., put the horses to work turning the cannon boring drill bit at 32 revolutions per minute) and measured the temperature of the water over a period of several hours. Rumford (1798) wrote,

The result of this beautiful experiment was very striking, and the pleasure it afforded me amply repaid me for all the trouble I had had, in contriving and arranging the complicated machinery used in making it. The cylinder, revolving at the rate of about 32 times in a minute, had been in motion but a short time, when I perceived, by putting my hand into the water, and touching the outside of the cylinder, that heat was generated; and it was not long before the water which surrounded the cylinder began to be sensibly warm…. At 2 hours 20 minutes it was 200°F; and at 2 hours 30 minutes it ACTUALLY BOILED! (pp. 91–92, emphasis in original)
What Rumford observed was heat produced in the friction of two metal surfaces (the borer rubbing the bottom of the cylinder). The heat was produced “in all directions, without interruption or intermission, and without any signs of diminution, or exhaustion” (Rumford, 1798, p. 98); in other words, the heat produced appeared to be inexhaustible as long as the boring machine ran and metal was rubbing together. Committed to the notion of conservation (the idea that nothing can be created out of nothing and nothing can be destroyed into nothing), Rumford concluded heat could not be a material substance, but it could be motion. In the case of the cannon boring machine example, he showed heat is motion, it can be continually recreated by mechanical friction and we can draw heat off the bodies in friction as long as the mechanical work continues (Simonyi, 2012, p. 368).

Although Rumford’s “beautiful experiment” looks definitive today, we learned from Simonyi and Coopersmith that his publication did not settle the debate at the time. According to Simonyi, his experimental results were accepted, but his conclusions were not. In fact, attempts were made to interpret his results in light of the heat substance theory (i.e., heat was an object). We think the concept of heat as motion was finally accepted after Einstein explained Robert Brown’s observation, using a microscope, in 1827 of pollen grains moving through water. Einstein showed how the “Brownian Motion” of the pollen grain could be explained by the kinetic energy of invisible moving atoms. The motion got more energetic as the temperature elevated, finally showing the temperature was connected to motion of atoms (Einstein, 1956). The idea heat is motion might have been more widely accepted before this, but we left that an open question and noted it along with the others (Figure 4.4 note d).

Let’s return to our thrown ball example. Rumford’s experiment provided an explanation for the apparent loss of the kinetic energy in this example. He showed that if friction is present, it would generate heat and, according to Simonyi, Rumford came quite close to recognizing the equivalence of mechanical energy and heat energy.

Still eager to get to learn more about energy transformation, we skipped ahead, over the meandering path of investigations into the nature of heat, to learn more about James Joule. Joule confirmed a lot of friction would produce a lot of heat. This meant we could now account for the kinetic energy that seems to disappear. While some of the kinetic energy of the ball is transformed into kinetic energy, some of the kinetic energy of the ball is also transformed in the process of friction (the ball and the surrounding air rubbing together) and transferred by heat into the air and the ball (and eventually to the Earth when it lands). In other words, some of the kinetic energy was “lost as heat.” What we still didn’t know was whether this was obvious to anyone in Joule’s time.

At this point we felt we were ready to learn more about what many have called the most important realization in science for the 19th century: Not only can energy be transferred between things (motion of a hand to motion of a ball), but energy
can also be transformed. As we mentioned earlier, Rumford did not realize he had not only conducted an experiment to defend the kinetic theory of heat and attack the substance theory of heat, he had also demonstrated mechanical energy could be transformed into heat energy and vice versa, even though this seems obvious to us today and is even a phenomenon we all experience every day. Asimov illustrated it with some great everyday examples: (1) we witness this transformation when we boil water for tea; (2) we see the heat of the gas stove burner can cause water to boil and then turn it to steam that rises into the air; (3) we indirectly witness this transformation every day when the heat of the sun raises countless tons of water vapor kilometers high into the air, so all the mechanical energy of falling water (rain, rapids, waterfalls, flowing rivers) originates from the sun’s heat; and (4) in our cars, we burn a source of fuel (gasoline) to create a series of controlled explosions that drive pistons and turn wheels and all the mechanical energy of the moving car originates from the heat produced by burning gasoline.

If Rumford was right, and heat was motion and heat came from the mechanical work done by the horses on the drill bit of the cannon borer machine, then any phenomenon that produced heat must be considered a form of energy or work store. An electric current in a wire can heat a wire, so electricity must be a form of energy. A magnet can cause current to flow in a wire, which heats a wire, so magnetism must be a form of energy. Light from the sun can heat up any matter, so sunlight must be a form of energy. Sound creates heat, so it must also be a form of energy. Could these claims be true? According to Coopersmith, it was James Joule (1818–1889), Julius Mayer (1814–1878), and Hermann von Helmholtz (1821–1894) who typically get credit for finally crystallizing the modern idea of energy and energy transformation, but we focused on Joule’s story since we learned he did many of the classic experiments often recreated in middle and high school physics classes to show that the implications of some of Rumford’s conclusions were accurate.

We learned from Coopersmith that Joule was the son of a brewer. As an adult he ran the family brewery as his occupation, but as a boy Joule was tutored by James Dalton (an English chemist, meteorologist, and physicist later known for his early work in developing the modern atomic theory). As an adult, science was a serious hobby for Joule, even though he was a professional brewer. In a series of experiments, Joule endeavored to show how a certain amount of work (by any energy source) would always produce a certain amount of heat. To do this Joule measured the heat produced by (1) an electric current through a wire, (2) the friction of water against glass, (3) the kinetic energy of turning paddle wheels in water, (4) the work involved in compressing gas, and (5) the friction of water, mercury, and cast iron. In all his experiments, Joule found a fixed amount of one kind of energy was converted into a fixed amount of another kind of energy and, if energy in all its varieties was considered, energy was neither lost nor created (Asimov, 1966, p. 99). The importance of Joule’s contribution was not the simple idea that one kind of energy could be changed into another. It was his mathematization of the transformation that showed the quantity was equal. He needed that evidence to
prove the idea of conservation of energy. The work of Joule and others shifted the application of conservation laws from work to energy.

Again, like Rumford’s, Joule’s reports to the Royal Society were met with complete indifference, and the conservation of energy principle still did not take hold until later under Lord Kelvin’s promotion (Simonyi, 2012, p. 377). Understanding energy storage, transfer, and transformation, however, eventually led natural philosophers to abandon the notion work could be conserved and to realize energy could be conserved. This is our current understanding and the notion we teach today (Figure 4.4 note e).

Reading and constructing this (very) rough history of the energy concept took a considerable amount of effort to construct (approximately seven 9-hour work days, about 60 hours). It is not a story we found in one source, but a story we created through multiple readings and conversations with colleagues and career scientists. It is the work we did before teaching as part of a project to rethink how to teach the energy concept to students in light of the new science standards. It is also not the only story we could have written and reflects the limits of our understanding at this time. Reaching our goal of establishing some cursory understanding of the history of the energy concept took persistence, confidence, curiosity, wonder, and doubt. Our investment, however, yielded a great reward—now we feel we have a better lens through which to view, select, modify, and adapt instructional materials for teaching energy concepts in the future, and we illustrate the ways that lens might influence these processes next. We are in the process of incorporating some of the ideas proposed next, but most are still untested so we cannot comment on their effectiveness at this time.

A NEW LENS FOR INSTRUCTIONAL PLANNING AND CURRICULUM REVIEW

All the scientific explorers we learned about in our literature search were studying what we now call energy, but they didn’t necessarily know they were studying energy. They were studying various interactions and changes observed in work, engines, motion, electricity, magnetism, light, and heat. Few set out to study energy, nor did most even define what they were studying as the ability to cause a change because that task was not possible until the definition of energy was created much later. Initially, energy was invented to describe what was conserved when work was performed. Then it became a tool to describe what was conserved when any change took place. Then it became the tool to describe what was transferred or transformed when a change took place. It also became a tool for accounting because being committed to the idea of conservation (nothing is created or destroyed) meant investigators needed to keep track of or account for all the work in a system. In other words, conservation always required an accounting tool. In the case of work (or change) for example, energy is an accounting tool used for keeping track of what is conserved about any change. This analogy is not commonly used in K-12 physics, but we believe it is one that should be explored and developed further.
As the findings in this field matured and people started to synthesize them, they began to describe some essential or fundamental tools, which are now generally considered important for science students to learn: conservation, closed and open systems, interaction, energy transfer between source and receiver, energy transformation, and energy chains. With the benefit of this hindsight, we novice learners now have a very sophisticated energy tool and can use it to create connections and common ground between independent phenomena and objects in a wide range of fields.

At the beginning of this chapter, we proposed there are two prominent types of tools for teaching and learning problem solving in science education: everyday tools and scientific or theoretical tools. When students learn problem solving in science by performing laboratory exercises, participating in demonstration activities, and solving specific problems, they are likely to construct and employ their existing everyday tools for thinking about energy. However, when students participate in these activities with the understanding they are learning theoretical tools, the hands-on work takes on a new meaning and purpose. It is notable the learning standards for science have consistently separated these types of tools into grade-level “content standards” (primarily comprised of everyday tools) and interdisciplinary “cross-cutting themes” or “unifying concepts and processes standards” (theoretical tools). This separation makes it difficult to see how teaching and learning requires attention to both types as described by Vygotsky in the earlier quote.

If we want students to understand a theoretical tool like energy we must introduce them to the broader systematic idea of energy and help them reinvent it while we also engage them in the everyday, concrete activities, which help familiarize them with the types of problems the theoretical tool helps them to solve. How did the lens we created from our literature review of energy and its history help us evaluate instructional resources intended to aid us in teaching both the everyday and theoretical tools can help students learn? We answer this question next as we continue describing our planning process.

Revisiting the Standards

After constructing a brief historical outline of a history of the contemporary energy concept tool we reread the NGSS section for DCI Energy and realized the collection of facts presented may have more serious flaws than just decontextualization. In this second reading, we recognized the K–2 performance tasks are so distantly and obscurely related to each other and/or to a useful energy concept that it is not clear how to make reasonable connections, never mind figure out how to make them relevant and meaningful to K–2 audiences:

• Make observations to determine the effect of sunlight on Earth’s surface.
• Use tools and materials to design and build a structure that will reduce the warming effect of sunlight on an area.
• Plan and conduct investigations to provide evidence that vibrating materials can make sound and that sound can make materials vibrate.
• Make observations to construct an evidence-based account that objects can be seen only when illuminated.
• Plan and conduct an investigation to determine the effect of placing objects made with different materials in the path of a beam of light.

After revisiting Figure 4.2 and Table 4.1, we generated several new questions in response to the NGSS K–5 learning standards for energy based on our inquiries:

• Sunlight is a type of electromagnetic radiation, so why isn’t it connected with the energy subtopic “electromagnetic radiation”?
• Sunlight is only one type of several energy transfer formats, so why is it the only one listed under the energy subtopic “conservation of energy and energy transfer”?
• The observation that sunlight warms the Earth’s surface (K–2 performance) is not an observation that leads to an understanding of the conservation of energy or to the notion of energy transfer. To what extent are students to understand the overarching principles of conservation and transfer and why?
• Why are “wave properties” highlighted as an energy subtopic?
• Sound is a form of energy transfer; when are students expected to learn this connection to energy?
• There are many chemical processes in everyday life that illustrate energy storage, transfer, and transformation. Why do the standards focus on photosynthesis (3–5 performance), a complex process career scientists are still trying to understand? Why is this the example used to show how energy can be transferred, stored, and transformed? How can it be used in conjunction with simpler systems to ensure successful learning and avoid confusion?
• The notion “contact forces transfer energy” (3–5 goal) has the potential to lead students to conceptualize energy as an object that can only be transferred when objects touch each other. How can we design lessons that avoid these simplifications that lead to future miscommunication?
• What does the fact “objects can be seen only when light is available to illuminate them” have to do with understanding the energy concept (K–2 goal)? The NGSS focus on our ability to see because of light reflection is puzzling because light reflection is not the central phenomenon that illustrates light as an energy transfer form. Plus, it’s not even true. We can use night-vision goggles to see the infrared radiation emitted by a warm object. As worded, this standard is not about energy at all; it is about the limitations of our eyes.
• The subtopic “relationship between energy and forces” refers to Joule’s conclusions, but can also refer to Newton’s studies of motion. Why limit the focus on collisions (K–5 goals), when a study of what a variety of interactions have in
common could help students build a deeper understanding of the relationship? When we focus on one type of interaction, then the so-called relationship looks like a specific case and it loses its intrigue and power.

These new questions were unsettling and revealed a level of muddiness to the NGSS we had not anticipated. On the other hand, these questions revealed how considering tool types could help us identify possible connections and questions that have the greatest potential to engage our students in the future and teach us (students and teachers) what types of problems scientists actually work on. It may also help us provide students with a context for them to consider whether they’d like to work on similar problems. We grew more and more comfortable with our doubt that the DCI-Energy standards (as presented) are an adequate guide for instruction.

Laboratory Exercises a.k.a. Hands-on Activities for Teaching and Learning an Energy Concept

Next, we began to review the various laboratory exercises we have conducted in the past with students and teachers to demonstrate particular science concepts related to energy. We wondered if these lessons were serving to complicate, confuse, or clarify students’ developing notions of energy and how we might improve these lessons (Figure 4.4 note f). Laboratory exercises are often referred to as hands-on activities in elementary science education. The purpose of these exercises is typically to reproduce a particular phenomenon, as well as the measurement method used to describe it. Then, through discussion between students with or without the classroom teacher, students rediscover or reproduce the scientifically acceptable explanation of the phenomenon under study. Often these exercises are reenactments or representations of historically important experiments. This latter point is rarely mentioned in the activity guidelines for teachers or in the instructions for students. Based on the findings from our energy inquiry, we have started to develop some simple ways teachers might begin to help students start to create more theoretical tools related to energy through practical experience and reflection. We organized these initial ideas according to units typically promoted for elementary school science teaching and learning, and briefly summarize our initial ideas next.

Work and simple machines. Upon reviewing a simple machines unit, we saw students often study simple machines and how they work in ways that imitate the French natural philosopher (physicist) René Descartes (1596–1650). Teachers could explain this to students and also share with them Descartes’s conclusion that all simple machines could be thought of as a system of a force applied to a weight. They could ask students, at some point during their investigations of simple machines, whether they noticed how each simple machine helps them move heavier objects than they would be able to move without the machine. Teachers could also ask whether students noticed they could move more mass with the machine, but in doing
so, it moved less far. Teachers might explain Descartes noticed the same things and read from his notebook:

The same force which can raise a weight, for example, of a 100 pounds to a height of two feet can also raise one of 200 pounds to the height of one foot or one of 400 to the height of half a foot, and so with others, provided it is applied to the weight. (Descartes as quoted by Coopersmith, 2010, p. 25)

They could have students compare Descartes’s examples with their own and decide whether they can conclude what Descartes concluded: With a simple machine we can move twice the mass we could without a simple machine, but we can only move it half the distance for the same amount of effort. At this point students could be presented with various problems such as:

- Why can’t we move any mass the same distance as we can without the simple machine?
- Why doesn’t the machine let us move a greater mass the same distance or even farther?
- Imagine a more complex machine such as a car with trunk full of bricks versus a large dump truck full of bricks. How far can each go on a gallon of gasoline fuel?
- Related to the question of moving a mass farther, do you think we can create a machine that runs forever? Why or why not?

It might be fun to end a simple machines unit with research related to the last question because students might be interested in learning about perpetual motion machines and why they cannot work. For example, perhaps since the invention of simple machines, humans were attracted to the quest for a perpetual motion machine—a machine that could run forever (and do endless work) once set in motion. The attraction to any worker is obvious. When grinding piles of grain into flour, one is forced to use muscle power on days when the waterwheels or windmills fail. Wouldn’t we dream about a perpetual motion machine, too? Lived experience certainly made people skeptical about such a machine and hinted something must be conserved, yet many still tried to invent such a machine. Students could learn more about the people interested in this type of machine and why. Based on what students were learning about simple machines, teachers could ask them what kind of problems students think a perpetual motion machine would need to overcome in order to work. Solutions to this question may or may not be more sophisticated than the scientists working more than 200 years ago.

By infusing historical accounts into units that focus on simple machines and work, we feel teachers can begin to introduce students to broader problem-spaces where they can apply their knowledge of work to new situations and begin to theorize work as intended by the instructional unit.

*Balance.* We’ve done a lot of investigations of balance with students in the past using instructional materials from the Full Option Science System (FOSS). They’ve
studied how to build a variety of structures that do not fall toward the Earth in the gravitational field in which we live. We’ve had them balance two-dimensional shapes made out of heavyweight paper on various edges and tips by moving its center of mass. We’ve had them create mobiles that balance unequal weights on their various beams. We’ve even had them figure out how to balance pencils on their points. Not all their configurations worked when they did their investigations. Many times (maybe even most of the time) the objects collapsed on the table or fell to the ground—in other words, they moved when we didn’t want them to. These failures are an opportunity to talk about using the concept of balance more broadly. Understanding structures and how to make them stand up (and not fall down) is the type of problem that interests structural engineers. Teachers can ask students to learn about (and explain) some of the most important discoveries or inventions in structural engineering we all rely on today.

As we reviewed the activities students usually do in this unit, we realized teachers could also ask students to describe the simple machines within the structures they had built and explain what balance means when working with a simple machine. A mobile is actually a simple machine—a series of levers suspended in the form of a mobile. Students should be able to use what they know about levers to show where the lever arm, fulcrum, and masses are in the system and then explain how the mobile works. The same is true for the system of the balanced paper and clips, which is also a type of lever students should be able to identify and explain.

Motion. Given the results of our energy inquiry we were a bit overwhelmed by the possibilities for adapting lessons on motion. One place to start might be to have students retrace classical experiments. By presenting them with various claims and asking them to test each claim and decide whether they agree and why, the historical experiment comes alive for the students (e.g., Galileo claimed once an object was in motion on a perfectly horizontal surface with nothing in its way it would travel in a straight line forever. How would students test this claim and decide whether they agree or disagree with Galileo?). Teachers could also infuse the unit with questions relevant to the energy concept, questions such as: Why do the balls we roll keep moving even after we let go? Why do the balls stop even when nothing touches them?

After our energy inquiry, we realized we need students to understand motion has intrigued natural philosophers, physicists, and scientists for a long time and why. To this end we think teachers could infuse the unit with questions asked by our scientific ancestors as well the questions we have today: Why does motion appear to depend on our perspective, or relative position, in relation to the object in motion? Does the Earth move, or do the sun, moon, planets, and stars move, and how do we know? How do living things move? Why does everything around us seem to move or fall toward the center of the Earth? How come things orbiting the Earth, like the space station and satellites, don’t fall down to Earth? How did we get to the moon?
How did Voyager 1 get beyond our solar system, and how far can it go? What moves nonliving things, and how do they cause other things to move?

Our reflection on the activities and sequencing of the Balance and Motion units in light of the energy inquiry led us to propose these more efficient ways to recontextualize the historical experiments students were already doing. It also challenged us to think about how teachers could develop these units further to tell multiple stories rather than one story about how we’ve collectively come to understand energy and motion are equivalent (or interconvertible).

Living things and food webs. As we analyzed our incorporation of energy concepts into our teaching of living things and food webs we were quite pleased to see the extent of our integration with energy concepts. The historical component, however, was lacking. Based on our energy inquiry, we identified another potentially useful line of questioning. Compelling questions are those grounded in the everyday observation that the work done by living things seems to appear out of nowhere. This was a classic question of early natural philosophers and teachers could use it to ask students their ideas (pre- and post-unit) about where this ability to move, work, repair, and grow comes from. For example:

- When a butterfly emerges from its chrysalis, where does the work of its wriggling body come from?
- When we raise our hand in class, where does the work of our moving arm come from?
- When a plant grows a new leaf or a longer stem, where does this ability to grow come from?
- When we break a bone or cut our skin, where does the ability to repair ourselves come from?
- When the pterosaurs flew during the age of the dinosaurs, where did the work of this flying reptile come from?

With research assistance, students could also investigate who studies these questions now and who studied them in the past.

Properties and phases of matter. When we looked at units on properties and phases of matter through our new lens from the energy inquiry, we were a bit chagrined to realize how most commercial curricula we have used ignore the fundamental connection between energy and properties and phases of matter. As we learned when we assembled various definitions of energy, energy can be thought of as a property of matter or another way to describe the properties of matter (because energy is matter and matter is energy). We can describe matter from the perspective of its use as a source of fuel, its use in chemical reactions, its use for moving other objects. This is an important connection for teachers to explore with students.
We also realized phase changes are examples of energy transfer, and once students are familiar with these teachers could ask them to study melting points and boiling points in more depth to learn more about what makes them so remarkable. Here are some possible scenarios we recommend for each.

**Melting point.** When students first take an ice cube out of a kitchen freezer its temperature is about –10°C. When they hold the ice cubes in their hands, the temperature of the ice cubes start to increase (they get warmer) and their hands start getting colder. At some point the ice cubes start melting. That is called the melting point, and it occurs at about 0°C (depending on the conditions). If students could measure the temperature of the ice while it is melting, they would see it is not getting any warmer. It is staying at the melting point until all the ice is melted. However, while the ice stays the same temperature their hand is getting colder and colder. Somehow heat from their hands is going into the ice cubes and causing them to melt, but not showing up as a temperature change. Where did the heat go?

**Boiling point.** With adult supervision, when students put a pot of cool water on a kitchen stove and turn on the gas flame under the pot, it causes the temperature to rise until it reaches 100°C, at which point it stops rising. When they put a pot of boiling water on a stove and turn on the same flame under the pot, the temperature of the water does not rise above its boiling point. (Note: it is a myth that water boils at 100°C under normal atmospheric pressure. In fact, the boiling point is fickle, according to Hasok Chang (2008), and can be effected by variations due to any impurities in the water, local pressure, the amount of dissolved air in the water and the container in which it is boiled). No matter how long students run the burner flame or how high they turn it, the temperature of the water never rises above its boiling point. When the water is cooler than the boiling point under those conditions the temperature rises, but when the sample reaches its boiling point the temperature stops rising. What happened to heat from the flame?

**Electromagnetism.** We noticed Joule’s experiments were not included in most of the units we have used in the past to teach electromagnetism. In fact, most of the units focus on superficial features of electricity and magnetism don’t necessarily help students understand the phenomenon very well. For instance, students learn how to create both series and parallel circuits using batteries, bulbs, motors, and wires, but they don’t learn much about electricity, batteries, bulbs, motors, or wires! This makes it even more difficult for them to understand the investigations or demonstrations showing the relationship between electricity and magnetism (e.g., observing a moving a magnet near a wire can generate electricity and running electricity through a wire can generate a magnetic field). Some questions we now believe might be appropriate for early introductions to electromagnetism as a form of energy include:
• What is a battery?
• Can the battery run the light bulb(s) forever?
• Can you lift all metal objects with your magnet (paperclip and metal desk or car)?
  What are the limits of your magnet?

These questions can be investigated directly and used to connect to the energy concept and show electromagnetism is a form of energy and can be converted into other forms.

Weather and climate. When teachers investigate weather and climate with students they could make connections between energy, weather, and climate by having them study how wind can be used to do work, not just what it is and ways to observe and measure it. They can also make connections to the early questions about work and show that inanimate objects like wind (moving air) and falling water can do work. By studying these questions, teachers can help students see how motion and energy are equivalent:

• How is wind generated (or how does air come to move as wind)?
• When we harvest wind energy, where does that energy come from?
• What makes rain?

They can also make connections to the present and the future by asking students how predicting weather has improved over time and why. Students can also study what kinds of tools meteorologists have today that help them make accurate predictions and what are open questions about climate and climate change.

Biogeochemical cycles. Initially we were not sure how we could help teachers make clear connections between energy and biogeochemical cycles, but our energy inquiry provided a few clues that we’ve outlined as possible avenues for student investigations.

Water cycle. What is the energy story in the water cycle? Our current understanding of the water cycle was only universally accepted in the 20th century, but first began to form 2,500 years ago. In ancient times, it was thought the land floated on a body of water and most of the water in the rivers had its origin under the Earth (as described by Homer). By 500 BCE the origin of rain was known and many people believed the water of rivers could be attributed to rain, but also from water rising up through the Earth. As far as we know, the first person to describe what we now think of as the water cycle was Bernard Palissy (1580 CE). His idea was tested and then published by Pierre Perrault in 1674 (Wikipedia contributors, 2014c). In Perrault’s description of Palissy’s comparison, he tested what is now our modern concept of the water cycle. Palissy conducted the first known quantitative test to settle the debate of whether or not the rain falling on the surface of the ground was
sufficient to supply water to all the rivers and springs (Dooge 2001). To do this, he selected a catchment system to observe. He retrieved three years of rainfall in the area to estimate the precipitation in the catchment. He calculated the runoff from one river (Upper Seine) into another (Gobelins) as well as the flow of the Seine and the height of the Gobelins. Using these measurements he calculated one-sixth of the rainfall could explain how the Seine was able to constantly feed the Gobelins.

By making close observations as Palissy did, students can learn evaporation is liquid water becoming water vapor that rises up into the air and sky (related to the phase change that occurs when water boils). This means water is being moved (against gravity) from the ground into the air. Possible questions might include: What makes the work of evaporation possible? What problems about the water cycle are of interest to us and other scientists today? What is water? How come it can be moved against gravity simply by heat?

**Rock cycle.** Our understanding of the rock cycle was developed fairly recently by J. Tuzo Wilson during the 1950s and 1960s, who modified James Hutton’s version from the 1700s. Students in the early grades often learn rocks erode when they are exposed to wind and rain, heating and cooling, and banging and rubbing against other rocks. They also learn mountains eventually erode to pebbles, sand, and silt over long periods of time. We can make connections to energy by examining the processes of erosion from an energy perspective and ask: What makes the work of erosion possible?

**Sound.** With our colleague, Catherine Milne, from the Scientific Thinker Project, we already made major modifications to the sound investigations we have used in the past. In this modified unit, students learn about Pythagoras and conduct similar experiments to those he did when he was trying to understand how various sounds were made by musical instruments. Students are asked whether they agree with each of Pythagoras’s claims after testing them in the lab. Once they learn sound is vibration and that vibrations can travel from a source to a receiver, we also have them explore historical models of how sound travels. Students learn about experiments and theories used to explain sound travel, including those of Aristotle, Vitruvius, Boethius, and Newton. In the future, we need to be alert to ways of helping students investigate sound from an energy perspective and show how sound is another form of energy.

**Light.** In the NGSS one of the major experiments students are instructed to conduct is a demonstration that sunlight can heat objects. It would seem the equivalence between light and energy is very easy to make, but based on our energy inquiry it is not obvious how to make that connection. One way teachers might help students establish the equivalence between light and energy is to focus their attention on heat. Historically, when heating was recognized as a form of energy transfer this recognition made possible the unification of various observations and conclusions.
into a single explanation. Recognizing anything that created heat must be an energy source means light is an energy source. In most elementary school units on light, students explore the properties of light including what happens when it is refracted, reflected, and absorbed. These explorations are intended to help students understand light behaves as a wave, but they lose the even more important message that light is a form of energy. This highlights the historical focus of science education on the theoretical understanding of a particular property of light rather than a holistic exploration of light and what it can do. By studying light from an energy perspective, teachers can help students think about various types of waves and how they transfer energy between objects.

This brief review of how to modify popular resources for teaching and learning an energy concept reveals the paucity of high quality instructional materials available to elementary classroom teachers for teaching this concept tool. Many teachers are afraid of teaching the energy concept incorrectly because they think they are not good at science. What many do not realize is they are often relying on mediocre tools for instruction that only serve to confuse earnest learners (including themselves). We hope this analysis above empowers teachers to demand better tools from publishers and to seek out writers and designers who reflect our approach. In the next section we describe some overarching resources and ideas that can be incorporated at any time and can help guide the process of making modifications to improve mediocre tools.

Theoretical Tools

There are many theoretical tools under the umbrella of the broader energy tool, including the notions of:

- Energy chain
- Energy equivalence
- Energy source
- Energy receiver
- Energy transfer
- Energy transformation

Each of these has to be reinvented with students so they can step back from the specific examples of energy forms from their practical investigations (e.g., light, heat, sound, wind, motion) in order to learn what these forms we experience every day have in common and how many ways they can be configured relative to each other. Should we choose to teach these in conjunction with the everyday activities, it is important the students understand these as tools generated in hindsight based on the results of a variety of experiments conducted over a long period of time.

Ideally, our future instruction on energy would be organized around these theoretical tools rather than around the separate activities listed previously (e.g., balance, motion, work, and simple machines), which only provide examples of
various tools and makes synthesis difficult for students. The only commercial curriculum for elementary school students that takes a similar approach is the Science Curriculum Improvement Study-3 (SCIS-3) unit on energy sources (Lawrence Hall of Science, n.d.). This was not too surprising, since the members of the original SCIS development team used Bruner’s theory of instruction, which in turn was influenced by Vygotsky’s theory of learning.

Children’s Literature Analysis Guide

After our energy inquiry, we reread a variety of science books on energy written for children and we analyzed them using the following guiding questions:

1. How is energy defined?
2. What tools for thinking about energy are presented (e.g., energy equivalence, energy transfer)?
3. What historical or contemporary scientists are featured, if any?
   a. How many were men?
   b. How many were women?
4. How are children represented (e.g., boys vs. girls, conducting investigations vs. narrating facts)?
5. How were men and boys depicted in images or photos in the book, and what were they doing?
6. How were women and girls depicted in images or photos in the book, and what were they doing?
7. What connections are made between:
   a. Past theories and contemporary theories?
   b. Explanations and everyday phenomena?
   c. Phenomena and models?
   d. Contemporary problem posing?
8. Are models misrepresented as discoveries or are they, more appropriately, represented as syntheses created by people?
9. What tools for thinking about science are promoted (e.g., anyone can contribute or only experts can contribute, it’s anonymous or it’s the work of real people)?
10. Is a single story presented, or multiple stories?

We selected a book from our library on energy to demonstrate how we used this series of questions as an evaluation tool and the results are presented in Box 4.1.

This media analysis guide can provide a quick reference for future use during planning and implementation. Teachers (and students) can paste the completed forms directly into the relevant texts for quick reference. Completed forms can also be stored electronically in a personal planning database. Completed forms can be especially helpful during the busy school day when teachers and students need to know quickly which source(s) might be the most helpful in response to student interests or other instructional needs.
Box 4.1.

Representing Scientific Problems in Children’s Literature
An Evaluation Guide

Topic: Bill Nye the Science Guy
Title: Energy: Discover the amazing story of energy – where to find it and how to make the most of it.
Author: Jack Challoner
Publisher: DK Eyewitness Books
Publication Date: 2012

1. How is energy defined?
   Energy is defined on page 6 as “Energy, defined as the ability to make things happen, cannot be created. Nor can it be destroyed.”

2. What tools for thinking about energy are presented (e.g., energy equivalence, energy transfer)?
   Examples of energy sources are presented (they are not called sources or receivers). The main theoretical tools presented about energy in general are the notions that (1) “all forms of energy are either kinetic or potential energy” (p. 16) and (2) the laws of thermodynamics describe how heat and other forms of energy behave (p. 26). The majority of tools for thinking are facts generated from experimentation.

3. What historical or contemporary scientists are featured, if any?
   Many historical and a few contemporary figures (including some ancients) are included in the book (approximately 57 individuals were named).
   a. How many were men? 57
   b. How many were women? 1

4. How are children represented (e.g., boys vs. girls, conducting investigations vs. narrating facts)?
   Only five children were depicted in photographs—three boys and two girls. They were not pictured as scientists, but in activity to illustrate a graph displaying the “Energy output by the human body.” One girl was “standing”, one girl was “dancing” ballet, one boy was “walking moderately quickly,” and one boy was “playing soccer.” One was depicted on another page watching TV.

(Continued)
Box 4.1. (Continued)

5. How were men and boys depicted in images or photos in the book, and what were they doing?
   Portraits = 26
   Conducting experiments = 18
   Other (recreation) = 3
   Other (work) = 1
   Fictional/other characters = 2 (Popeye; Vishnu)

6. How were women and girls depicted in images or photos in the book, and what were they doing?
   Portraits = 1
   Factory work = 5
   Housework = 3
   Nursing = 1
   Other (bathing) = 1
   Other (talking on telephone) = 1

7. What connections are made between:
   a. Past theories and contemporary theories?
      There are a few examples of past theories that were “proven incorrect” (p. 18). For example, the sections on “Imponderable fluids” and “Heat energy” describe various experiments conducted to support or refute the theory that heat is a particle or fluid or the theory that heat is the motion of particles (matter). In another example, the section on “Electromagnetism” (pp. 22–23) mentions the evolution of thought about electricity and magnetism from the idea that they were each fluids passing between materials to the idea that they were two properties of the same “natural force.” Several key experiments that led to the shift in thinking were described.
   b. Explanations and everyday phenomena?
      There are many examples of (partial) explanations of everyday phenomena including photosynthesis, greenhouse effect, how mills work, what temperature is, what heat is, what friction is, how a steam engine works, how a combustion engine works, how a steam power plant works, how microwave ovens work, how we measure energy, etc.
   c. Phenomena and models?
      On nearly every page, there is a phenomenon represented by a model. For example, “Potential Hill” is used to explain the difference between potential and kinetic energy (p. 15). A drawing of “imponderable fluids” as little particles is used to demonstrate the theory of how heat, electricity, and magnetism “flowed” between objects (p. 19). Models
that fell out of favor were included as well as models that are now widely accepted.

d. Contemporary problem posing?
Most of the sections highlighted prominent historical investigations that solved or introduced questions or problems of the time. The author did not highlight what remains to be discovered in the various subfields covered in the text. Only at the end of the book in the sections on “Alternative energy,” “Making the most of energy,” and “The origins and destiny of energy” are contemporary problems raised (along with possible solutions). Very few open questions are raised for the reader.

8. Are models misrepresented as “discoveries” or are they, more appropriately, represented as syntheses by people?
The author was careful to use words such as: showed, experimented, investigated, thought, observed, mistakenly thought, noticed, measured, invented, believed, explored, explained, found, improved, realized, detected, predicted, and suggested. The author did use the words discovered and discovery in the section overview text, but rarely in the sidebars detailing an individual investigator’s contribution. Models were represented as the synthesis of specific people or groups of people, they were not presented as the products of anonymous workers.

9. What tools for thinking about science are promoted (e.g., anyone can contribute or only experts can contribute, it’s anonymous or it’s the work of real people)?
Science is a stockpile of facts. These facts are generated through experiments and investigations, which are conducted by individuals to support or challenge a particular hypothesis or theory. Science is the work of real people, but they are only adult males. A single experiment can settle a debate between theories. Scientists invent and/or use elaborate instruments to conduct their investigations. Scientific theories are developed over time, but not necessarily deliberately or with organized intention.

10. Is there a single story presented or multiple stories?
Overall, this book presents multiple stories. All are incomplete, but it is a good source to learn about some basic questions and investigations related to learning about energy. Some of the stories are oversimplified to the point of being inaccurate, so it will be important to keep the contents problematic.
Getting into the habit of developing and using media analysis guides like this can help teachers keep a critical eye on their library and the additions they prefer. Most science books for children are expository texts with and without:

- Relevant connections to everyday life.
- Troublesome representations of science.
- Adequate explanations of models.
- Historical context.

Knowing what is lacking helps to identify other sources that can fill the gaps, including (auto)biographies, history of science texts, original texts, and various digital media options. Due to the interdisciplinary nature of energy, it will be covered in a range of books about fields in the physical sciences, life sciences, earth and space sciences, and environmental sciences. The exercise of inventorying a library for energy concepts means teachers can create a list of titles that are otherwise separated by subject into discrete book bins and potentially be difficult to locate without a reference list. A blank analysis guide is provided in Appendix G. We encourage you to try this evaluation out on your own library or create your own guide for this purpose.

Engaging Students as Researchers

Although there are many existing instructional resources for teaching the energy concept, we were disappointed to find the collection was rather homogeneous in its approach—teaching through example and transmission rather than through problem solving and tool development. After completing the energy inquiry, we felt some relatively minor additions could help us shift students’ efforts to tool development, including two student-centered research projects: (1) a peer and community study and (2) an everyday usage study.

Peer and community study. In this type of study, we position students as researchers and ask them to interview one or more research associates (e.g., classmates, peers, family, community members, teachers, relatives, friends). In the case of energy, students could ask them to:

- Name three to five things they think they know about energy.
- Tell the student-researcher how they came to know these things about energy.
- Tell the student-researcher why they think these claims about energy are true or trustworthy.
- Tell the student-researcher how they might convince someone else these claims were true or trustworthy.

Using the results of the interview teachers can work with students to: (1) create possible definitions of energy; (2) discuss our confidence in, and questions about, the definitions; (3) inventory possible facts/claims about energy; (4) discuss our
confidence in, and questions about, these claims; (5) inventory questions and wonderings about energy; and (6) propose how one might investigate energy based on the information from the interviews. Using this interview tool to position students as researchers of peer and community tools for thinking before introducing canonical science tools is a strategy discussed in more detail in Chapter 5.

Everyday usage study. In this study, students can use the following prompt with their research associates to inventory how many ways the word energy is used in everyday language. Prompt: “Let’s work together and use the word energy in as many sentences as we can.” If students or their research associates have trouble with how to respond to this prompt, teachers can model one or more of the following responses as examples:

- She had a lot of energy.
- Shonika has a lot of negative energy.
- I had one of those energy drinks at lunch.
- We learned it’s important to turn off the lights and conserve energy.
- Food gives me the energy I need to play.
- I don’t have much energy.
- There’s a bunch of kinds of energy, like the sun and electricity.

Using the results of the reactions to this prompt, teachers can work with students to create a list of all the ways energy is used in their everyday language. For example, maybe the word is used to refer to:

- An object (e.g., an energy drink, the sun, or electricity)
- Something we have inside us (potential) (e.g., “she has a lot of energy”)  
- Something that allows us to do work (work storage, energy for work) (e.g., “turn off the lights to conserve energy”)
- An emotional state (sad, slow, happy, hyper) (e.g., “negative energy,” “I don’t have much energy”)

It doesn’t matter what or how many categories are generated; what matters is teachers and students make an effort to analyze the statements and roughly group them by similar features so students can see how versatile the word has become in our everyday lives. Teachers can to return to the list if confusion arises when students are trying to adopt the meaning of the term when it is used as a tool for scientific pursuits.

CONCLUSION

The questions of this chapter were: What kinds of problems do scientists work on, and would I like to work on the problems of science? What kind of answers are children and teachers learning when they ask these questions in their science classes:
• Are they learning that scientists are older men, usually white, who are genius, gifted, or have a natural talent for scientific thinking, or are they learning that scientists, as a group, are as varied as the people in their school (echoing the quote from Medawar in Chapter 3)?

• Are they learning the problems of science are too complicated for the likes of a young child and their teachers, or are they learning that the problems of science range in type, subject, and complexity? Are they learning that anyone with access can participate and contribute to science?

• Are they learning that when scientists use a specific method they will arrive at the correct answer, or are they learning that scientists routinely use, adapt, modify, and invent methods to investigate assumptions and seek answers to questions? Do they learn there is no guarantee that a particular method will yield a particular result?

• Are they learning that before they can be scientists they first have to reproduce well-understood facts and explanations about the world, or are they learning they can start being/becoming scientists today by wondering about and trying to explain phenomena they experience in their everyday lives? Are they learning they can start now to pursue their interests (e.g., space travel, dinosaurs, animal consciousness) or career goals (e.g., nurse, doctor, teacher, meteorologist, volcanologist)?

• Are they learning to blindly follow instructions, books, TV, and films to find out what their interests in science should be, or are they learning they can control and develop their own interests and use instruction, books, TV, and films to advance their own learning?

We can find more ways to interest children in learning science if we monitor how we represent science, the problems of science, and the types of people who can solve scientific problems from a learner–scientist perspective.

When we first drafted this chapter, we accidentally constructed a single story of energy and also attempted to provide foolproof instructions for the best way to teach energy tools for thinking. It was only in revisions that we realized what we had done and rewrote the energy story as presented here. By embracing and promoting a single story of energy in our first draft, we had ignored our own theory of instructional design. Why is the single story genre so attractive in science and science education? We think it is because science teachers and teacher educators (including us) are all eager to transmit the right information to students. They are excited about tools for thinking such as energy and they want their students to be excited about learning these tools. They see the power and value in understanding and using these tools and they work hard to communicate this to students. All these good intentions routinely lead teachers and researchers to construct concepts as single (correct) stories for students to accept and learn. Instead we want to strive for a reasonably well-researched story that teachers and students keep problematic
and recognize as one of many possible stories. In closing, we want to be clear that, while this chapter is a good place to start, or continue, constructing a story of energy, the story itself should also be kept problematic as you use it, test it, and expand it. As long as teachers and students approach any single story with interest, curiosity, a little bit of doubt, and an understanding that it is one of many parallel or possible stories, we can help others do the same.
CHAPTER 5

CLASSROOM RESULTS FROM A KNOWLEDGE AND KNOWING STUDY

How Do I Know What I Know? How Do Scientists Know What They Know?

Science is the belief in the ignorance of experts.

—Feynman, 1969

Engaging in research is empowering. We are in control of the questions we ask and the conclusions we draw. Research structures our thinking and communications. Being thorough and inquisitive implies paying attention to the context(s) of what we are studying, the ideas we are generating, their consequences and implications, and the perspective(s) we are representing. What can we do to engage our students in research right now with minimal preparation—research they can expand and transform for their own purposes, research we can use to teach the nature of knowledge as an action and the nature of facts/information as tools for thinking? We can ask them to study their own knowledge-acts and those of their teachers, friends, and family (including tool production and reproduction). We can ask them to study the knowledge-acts of authors or anyone of interest to them. What can research on knowledge-acts look like? How can we support our students doing it? For our purposes in this chapter, such a research program should include at least the questions: How did I come to know what I know? And how does this compare to how scientists know what they know?

In this discussion, we provide a set of foundational tools that can be used to engage students in what we think can be a lifelong research project. The research tools we present were designed to be used regardless of subject area or grade level, and we have used them with students as young as 5 years old. In the Introduction we made the argument science education should reflect a learner–scientist perspective rather than a discipline perspective (Figures 1.1 and 1.2). We believe organizing science education from the perspective of the discipline alienates new learners and perpetuates a variety of myths about science, including the nature of scientific knowledge and who can be/become a scientist. The tasks, protocols, and guides presented in this chapter were designed to be yet another means to dispel these myths
and make it easier for students to engage in the activist project of being|becoming scientists.

The physicist Richard Feynman made the opening quote when he was speaking at a National Science Teacher Association conference in 1966. In that speech Feynman was asked by the president of the NSTA at the time (James DeRose) to respond to the question “What is science?” and in response he told a childhood story of how he learned from his father what science is. Feynman learned science depends on people who actively doubt (not just question) the stockpile of facts generated by experts because they are always incomplete—a partial story. His comment, “Science is the belief in the ignorance of experts,” packs quite a punch at prevailing assumptions about being|becoming a scientist. This sounds like a pretty cheeky statement, but if we stop and think about our own learning process it is often propelled by questions of wonder, exploration, and creativity, which are usually home to a bit of doubt. Doubting assumptions can also propel our activities.

• “Why do I have to do it that way?” suggests I might doubt the knowledge of the authority that tries to direct my actions in a particular way.
• “How do they know it’s because of that and not this?” indicates I might doubt there is only one explanation or I might even doubt the explanation given.
• “What if I did this next instead of that?” might arise from the doubt an initial approach would be more effective than an alternative that hasn’t been suggested or created.
• “Just because it works under those conditions doesn’t mean it will work under these conditions,” suggests I doubt the generalizability of this method or tool across this particular set of conditions.

These complex questions not only assume there are multiple perspectives and solutions to a problem, but also represent seeking out alternatives. These questions are integral to any learning process, but we don’t typically use them for research on knowledge-acts and how we perform them. Although we wanted students eventually to ask these perspectival questions, we first wanted them to engage in research on their own knowledge-acts and those of the people in their immediate life-worlds. We refer to this student research project as the “Knowing and Knowledge Study” (KKS). This study had three major aims:

• To raise up the everyday practices of saying, “I know,” “I agree,” “I’m not convinced,” and “I trust” for inquiry and analysis in order to learn how people of all walks of life, including scientific thinkers, achieve these knowledge-acts.
• To develop and employ versatile and intuitive research tools and protocols that reflect a learner–scientist perspective.
• To provide a research infrastructure that supports young student-researchers and their research associates in purposeful and meaningful work, but allows teachers
to focus on assessment and instructional design in response to their findings and interests.

The KKS was initiated with third- and fourth-grade students and teachers who used the following questions in their investigations:

- What do we mean when we say we know something?
- What is something we know about ____?
- How did we come to know that about ____?
- Why do we think what you know about ____ is true or trustworthy?
- If we had to convince someone that what we know about ____ is true or trustworthy what would we do?
- How do we decide to trust a source (or how do we decide that a source is trustworthy)?

These questions were meant to prompt reflection on individual and collective knowledge-acts. Analyzing our answers drives us to explore, confront, and even change our learning habits, beliefs, and assumptions about knowledge and knowing. Analysis can take many forms, but some examples explored by our elementary students included:

- What sources do we use most frequently in our knowledge-acts? Why?
- What sources do we use least frequently? Why?
- Do we tend to believe what we read no matter what it says or who writes it? Why or why not?
- Do we tend to believe what we read only when it is consistent with our own personal experience? Why or why not?
- Do we tend to trust what parents, teachers, and older siblings tell us, but not younger siblings or peer-group friends? Why or why not?
- Do we tend to trust our senses and experiences over other sources, or do we tend to defer to others? Why or why not?

Students (or teachers), who tend to defer to others or tend to believe everything they read in the course of these research projects can be encouraged to develop instructional tools and activities (e.g., cost–benefit analyses) that help them rethink their practice and take action to change it.

*Studying Knowledge-Acts with an Interview Protocol*

To engage students immediately in a study of knowledge-acts as part of the KKS, we asked students to interview peers and adults in and out of school. The people who helped them in their research (e.g., by serving as interviewees or research
participants) were referred to as research associates, or RAs. We provided students with a KKS–Interview Protocol (KKS-IP; Figure 5.1). In the KKS-IP the wording and order of all the questions were the same for every RA.

The questions of the KKS-IP were originally developed as part of a larger project investigating how to teach the nature of scientific evidence through a study of the production of tools for thinking and knowledge-acts. The question “Tell me something you know about ___” was designed to capture knowledge claims—facts, ideas, information, and theories people felt confident about using and sharing with others in their daily lives. There was some discussion about whether the question would be less threatening if it was worded “Tell me what you think you know about ____,” but then the responses couldn’t be labeled as claims and we couldn’t be sure the RA had shared a claim in which they were confident. The question “How did you come to know that about _____?” allowed the RA to indicate the source and process of their tool production and helps students study the source and process of tool building in science. The remaining two questions, “Why do you think what you know about ____ is true or trustworthy?” and “If you had to convince someone that what you know about ____ is true or trustworthy, what would you do?” were designed to solicit evidence from RAs within authentic contexts—contexts in which they would typically marshal evidence if asked.

This design was chosen in the hopes all RAs would interpret each question the same way, and any differences found in the responses between RAs would be due to their beliefs rather than variations in their interpretations of the question (e.g., Denzin, 2009). This type of interview protocol is commonly used in the social sciences to solicit and compare the opinions, beliefs, values, and attitudes of people regarding a particular problem. For example, a sociologist interested in how children view themselves as learners might use a structured interview to elicit descriptions from children about learning and learners. In our case, however, we used it to design a tool to help students learn how knowledge-acts are performed by themselves, their friends, and others in everyday life and in science. It was intended to position students as researchers and provide them with a means to collect information about how they and the people with whom they interact on a daily basis came to know what they know and to compare these processes to how the scientists they study came to know what they know. In other words, students used the KKS-IP to investigate how they and others learn about the world. Unlike the classic structured protocol used by some social scientists in which the interviewer cannot modify the questions or aid RAs in interpreting the questions in any way, student-interviewers were allowed to help their RAs interpret the question as intended as well as ask their RAs follow-up questions as they wished.
**Learning about Sound**

Claims and Evidence

Interview someone (a relative, neighbor, teacher, etc.) and write her or his answer to each question on this chart. Ask them to tell you five (5) things they know about sound. You can interview more than one person if the first person cannot think of five things they know about sound.

<table>
<thead>
<tr>
<th>Who did you interview?</th>
<th>(1) Please tell me something you know about sound.</th>
<th>(2) How did you come to know this about sound?</th>
<th>(3) Why do you think this is true?</th>
<th>(4) If you had to prove this, what would you do?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neighbor #1</td>
<td>1. That it vibrates of materials.</td>
<td>Because when I listen to music I could feel a vibration.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>That it vibrates off materials</td>
<td>I would play music.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Her teacher told her</td>
<td>I would play that music.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighbor #2</td>
<td>2. Sound can be soothing and irritating</td>
<td>Personal experience</td>
<td>Candid camera</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sound can be soothing and irritating</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Overall, the interviews served as an engaging and easy way for students to gather many examples of claim–evidence conjectures, which we could then analyze (with teacher mediation) for trends including common habits, beliefs, and assumptions. Students could further interrogate any identified trends in subsequent research cycles focused on questions like those introduced at the end of the previous section. Although the KKS-IP was designed for teaching and learning the nature of scientific evidence, it soon became clear this interview protocol could be used at the beginning of all learning units to introduce new concept tools students would be studying. First, we describe how we introduce the protocol to students and then we discuss its merits as an alternative to the currently popular KWL, KLEW, Accountable Talk, and structured probe approaches.

To introduce the KKS-IP to students for the first time, we conducted a whole-class activity, which took about 1 hour. In the Scientific Thinker Project study, we provided instructions in a Teacher Guide (see Box 5.1) and our teacher-researcher colleagues had little trouble integrating it into their instructional time.

To give you a sense of how implementation of these instructions might play out in the classroom, let’s look at transcripts from two fourth-grade classes that participated in the early research project in which we developed this learning task. We worked with 126 third- and fourth-grade students and nine teachers the year these transcripts were generated, as part of the research study developing these instructional materials. According to the classroom teacher’s records, about 17% of the group was receiving special education services and 29% was receiving English as a second language (ESL) services. About half of classes 4A and 3A were comprised of students receiving special education services and each was taught by two teachers, one with a general education teaching certificate for grades 1–6 and one with a special education teaching certificate or dual certification (general education and special education). The remaining classes (3B, 3C, 4B and 4C) all had 10–15% students receiving special education and/or ESL services and one teacher certified in childhood education.

Transcript 5.1 gives us a sense of how Ms. Robinson and Ms. Tabaz (Class 4A) introduced the lesson. First, they told students they were going to begin a study of how we know, make decisions, and think (turn 1). Then they asked how we can find out what people know and how they know it (turn 1). After about 10 minutes of discussion (using the Accountable Talk method reviewed later in the chapter), they asked the class what it means to say we know something (turn 2). After discussing this for about 3 to 4 minutes, the teachers modeled the interview protocol students would begin using as part of their new research project on how people know various tools for thinking. The following abridged transcript illustrates some of the student responses.
Box 5.1.

The Knowledge and Knowing Study, Day 1—Excerpt from the Scientific Thinker Project Teacher Manual

Introducing the Knowing and Knowledge Study-Interview Protocol and starting the research on knowledge-acts project.

The purpose of the first few days is to provide students with experiences that allow them to reflect on:

1. Types of information and ideas students and others think are true or trustworthy, and their reasons for believing those ideas.
2. How they know what they know and about their beliefs.

Suggested here are some activities to give students opportunities to express their thoughts and begin to learn from others.

Materials: blank chart paper and pens, student name sticks, evidence notebooks, pencils, poster with organizing questions, scenario cards

1. Introduction

Provide an introduction to the work students will be doing over the next 3–4 weeks. Explain that students will study themselves, as well as other people (i.e., their research associates) and perform case studies of scientists.

Explain that when we do research like this with people we are going to call the person who helps us with the research we are doing a research associate or an RA.

(Possible script) “We’re always learning new things in school and at home and everywhere we are, but we don’t usually talk about what we know and how we know it. Over the next few weeks, we’re going to be studying what many types of people say they know and how they know it.”

2. Tools for thinking and knowledge-acts

Questions for discussion:

- When we say we know something, what does that mean?
- What are some examples of things we know?
- How do we know these things?
- Why do we think the things we know are true or trustworthy?
- How do we decide when to believe what someone else says they know?
- How sure are we about what we know?
- How do we convince others of what we know?
- How do we decide we need more information, and how do we get it?

(Continued)
Box 5.1. (Continued)

To get the discussion started, begin with a (brief) whole-class discussion (5–10 minutes) on the first question:

• When we say we know something, what does that mean?

Next, have students work in pairs and interview each other with a focus on questions 2–4. Interviewers should take notes and be prepared to tell the whole class what their RAs said (in the following format):

• What my RA knows (something my RA is sure is true).
• How my RA knows it.
• Why my RA thinks it’s true (why my partner trusts her/his knowledge).
• What my RA would do to convince me it’s true.

Provide time for students to interview an RA and find out answers to each one of these questions.

If students say they don’t understand what they are supposed to do, it might be necessary to model an interview for them. Below are listed some claims to explore in model interviews. If you use an example not shown, be sure to limit the examples you use to observations of the natural world. Avoid personal preferences for now (e.g., avoid “I know I like cookies”).

• I know/I am sure that if you swallow your gum it will not stay in your stomach for 5 years. (developed by a fourth grader)
• I am sure that butterflies do not fly in the winter. (developed by a third grader)
• I am sure dogs don’t drink milk. (developed by a fourth grader)
• I am sure my dog eats meat, but he doesn’t eat fish. (developed by a fourth grader)
• I am sure dinosaurs are big. (developed by a third grader)
• I am sure the milk in the refrigerator is cold.
• I am sure the trees will blossom in the spring.
• I am sure the snow will fall in the winter.
• I am sure when I talk I will make a sound.
• I am sure pigeons eat breadcrumbs.
• I am sure honeybees pollinate flowers.

(Continued)
3. Students share findings from interviews

After students have had time to talk, ask a few students to report on their explanation by asking each student to tell the class what their partner said he/she knew, how he/she knew it, and why he/she believes it.

Record their reports on chart paper (or a computer file) and save the chart/file for later instruction. As necessary, ask each interviewer follow-up clarifying questions to ensure that you’ve captured the idea clearly. Ask the presenter’s classmates whether they have any comments, questions, or suggestions before proceeding to the next presenter.

Remember to tell the students they did a good job listening, recording, and reporting what their RA said and let them know that these are skills that are used by scientific researchers everywhere (you can even ask them why they think it is useful to be able to listen, record and report).

4. Homework assignment

Ask each student to recruit and interview another RA for homework (e.g., a relative, neighbor, friend, parent, teacher, counselor). Each interviewer should ask an RA to tell him/her five things (facts, information, ideas, theories) they know about [fill in topic], how they came to know each of those things, why they think each is true or trustworthy, and what they would do to convince someone else to agree that the information is true or trustworthy. Ask students to record the RA’s responses on a handout (see Figure 5.1) or in their science journals.

If students want to interview more than one person he/she can ask each RA for one or two things they know, but they should try to get at least five responses total.

Discuss the type of information they will be gathering and possible interview strategies that will help them guide their RA. For example, if an RA says “I like sound” in response to the question “What do you know about sound?” the student interviewer will need to try to find out more and might follow up with, “That’s great, what do you like about sound?” Depending on the types of answers RAs provide during their interviews, student-interviewers may need to perform some follow up interviews on Day 2 (with guidance from teacher).

[Note. This example could be used also to probe the differences between “liking something” versus “knowing something.”]
Transcript 5.1. Introducing the Knowledge and Knowing Study (Class 4A, Week 1, Day 1)

<table>
<thead>
<tr>
<th>Transcriber</th>
<th>Speaker</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tn</td>
<td>Ms. Tabaz</td>
<td>((Introductory statement)) Okay, so for the next couple of weeks we’re going to be thinking about what/how we think. We learn things in school, out of school, at home, in the playground, on the weekends, when you’re on vacation; you learn things whenever you go somewhere. Every day. Depending on what it is you learn something, but—and then sometimes you share it and we just assume that what you say is true. That you know it. But now we’re going to take a look at how you know it, or what made you decide that, or how are you thinking about that. I know it sounds a little confusing right now, Jaden, but it’s actually going to be really fun and interesting and so we need to start thinking about how we think. So, the first thing that we’re going to talk about is: How do we find out what people know and how they know it?</td>
</tr>
<tr>
<td>Ms. Tabaz</td>
<td>2 Ms. Tabaz</td>
<td>When we say we know something, what does that mean?</td>
</tr>
<tr>
<td>Anita</td>
<td>3 Anita</td>
<td>It’s like a claim.</td>
</tr>
<tr>
<td>Ms. Tabaz</td>
<td>4 Ms. Tabaz</td>
<td>What do you mean by claim?</td>
</tr>
<tr>
<td>Anita</td>
<td>5 Anita</td>
<td>Like, like, umm, I claim that um, that um, that this classroom is this is the biggest classroom I ever saw. Like, I’m claiming that it’s true and, like, when you go to the airport you claim that, “you will be really late.” So you’re saying that that’s really, like=</td>
</tr>
<tr>
<td>Amelia</td>
<td>6 Amelia</td>
<td>=You know something.</td>
</tr>
<tr>
<td>Anita</td>
<td>7 Anita</td>
<td>Yeah, that you know something and you’re trying— you’re trying to say, you’re trying to make people— you’re trying to convince people to believe you.</td>
</tr>
<tr>
<td>Ms. Tabaz</td>
<td>8 Ms. Tabaz</td>
<td>Okay, so you’re trying to convince people that what you’re saying means something.</td>
</tr>
<tr>
<td>Xing-fu</td>
<td>9 Xing-fu</td>
<td>Chase.</td>
</tr>
<tr>
<td>Or, like, when you ask people. Like, it’s, like, when you ask, like, when you know, like, when you say something and, like, and you do not know mean— you do not know what it means or you do not know what it looks like. It’s like the same thing as investigate or, like, look around and, um, and, like, like, when you can’t find things and then, uh, like, go back and tell somebody, like, like, how they—they can see it. You know, like, like, what does it mean that if they really saw it or did they know what it means.</td>
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(Continued)
CLASSROOM RESULTS FROM A KNOWLEDGE AND KNOWING STUDY

Transcript 5.1. (Continued)

<table>
<thead>
<tr>
<th>In</th>
<th>Speaker</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Ms. Robinson</td>
<td>So if they know something, that means they really saw it? Is that what you’re saying?</td>
</tr>
<tr>
<td>12</td>
<td>Chase</td>
<td>Yeah, yeah.</td>
</tr>
<tr>
<td>13</td>
<td>Ms. Robinson</td>
<td>Okay.</td>
</tr>
<tr>
<td>14</td>
<td>Ms. Tabaz</td>
<td>What else could it mean when you say that you know something? What does it mean?</td>
</tr>
<tr>
<td>15</td>
<td>Eli</td>
<td>It means like, it means, like, um, when, um, when you know something it means, like, it means that you know information about stuff.</td>
</tr>
<tr>
<td>16</td>
<td>Ms. Tabaz</td>
<td>Okay, and how would you know that information about stuff?</td>
</tr>
<tr>
<td>17</td>
<td>Eli</td>
<td>Like, um—</td>
</tr>
<tr>
<td>18</td>
<td>Amelia</td>
<td>Maybe somebody told you?</td>
</tr>
<tr>
<td>19</td>
<td>Eli</td>
<td>Like, you researched, like, you research it. Like, you researched the information that you want to learn about.</td>
</tr>
<tr>
<td>20</td>
<td>Ms. Tabaz</td>
<td>So you already researched it, excellent. Chase, you remember?</td>
</tr>
<tr>
<td>21</td>
<td>Chase</td>
<td>Uh-huh.</td>
</tr>
<tr>
<td>22</td>
<td>Ms. Tabaz</td>
<td>Okay.</td>
</tr>
<tr>
<td>23</td>
<td>Chase</td>
<td>Um, like, if you— if it really like happened. And uh, and, like, it happened, uh, like it really happened before. And, um like, before, like, said someone, like, you really had said it someone. And they might have it— they might, like, think, like, two thumbs up, so like ((inaudible)).</td>
</tr>
<tr>
<td>24</td>
<td>Ms. Tabaz</td>
<td>Okay, because it actually happened before. Jacob, do you have something to add?</td>
</tr>
<tr>
<td>25</td>
<td>Jacob</td>
<td>((Shakes head no.))</td>
</tr>
<tr>
<td>26</td>
<td>Ms. Tabaz</td>
<td>Anita.</td>
</tr>
<tr>
<td>27</td>
<td>Anita</td>
<td>It also [means] to say something that you know. Like, in science if there’s— like, if Ms. Malony said, like, a iron object will stick to a magnet and if you have a magnet on it and then it sticks and then, and then, um, they tell you that that’s true then you could agree or disagree or it could be an opinion or it could be a fact.</td>
</tr>
<tr>
<td>28</td>
<td>Ms. Tabaz</td>
<td>Okay.</td>
</tr>
<tr>
<td>29</td>
<td>Xing-fu</td>
<td>Oh, that’s, like, oh yeah, it, like, when they ask, like, when you ask a question to somebody and, like, some people agree or disagree, like, from other people.</td>
</tr>
<tr>
<td>30</td>
<td>Ms. Tabaz</td>
<td>Okay. So, that’s actually going to take us into an activity that we’re going to do.</td>
</tr>
</tbody>
</table>
We had interviewed the students prior to instruction and knew most of them understood the meaning of the question “What do we mean when we say we know something?” and provided interesting answers. However, Mr. Archer (Class 4C) did not feel comfortable introducing this question to his students. He decided to integrate the lesson into his teaching a bit differently. Let’s look at what he did (Transcript 5.2). He began by explaining to students that they would be conducting research on how people know what they know. He proceeded to recreate the interview protocol by asking students first, “What are some things you know?” which he followed by asking, “Why are you so sure you know these things? How do you know these things?” After this discussion (about 15 minutes), he introduced the KKS-IP students would use in their research project.

Both approaches emphasized one of main aims of the study—raising up everyday practices to learn more about knowing and knowledge. All of Mr. Archer and Ms. Jasmine’s (Ms. Jasmine was a student teacher) students participated in the discussion, indicating they felt comfortable sharing their ideas and were interested in participating. This level of engagement by students in all classes indicated the approach was viewed as relevant, meaningful, and enjoyable to students. At this point, they all felt confident they could conduct the interview protocol themselves and everyone successfully completed the homework interview.

Introducing Claim and Evidence Tools for Thinking

Once students had gathered a number of claim–evidence conjectures from their RAs, we were ready to introduce claims and evidence as tools for thinking. Introducing these terms once was sufficient; this particular activity did not need to be repeated.

One difficulty with recognizing tools for thinking, such as claims and evidence, in our everyday knowledge-acts, is their ubiquity and familiarity. Because students produce claims and evidence in their daily lives, and they witness others doing it all the time, it was important to find ways to highlight these tools and their re/production processes. We found that the easiest way to do this was for teachers to codevelop working definitions with students using their results from the KKS-IP.

Our teacher-researcher partners started by explaining to students that during the interviews each RA made a claim when they told the interviewer something they knew or something they were sure was true. Then they added the label claim to the “What they know” column on the class chart and asked students to propose a definition of claim. After recording their responses the teachers consolidated them to generate the definition: “A claim is something we say as if it is true.” A sample of completed classroom charts for the term claim is shown in Figure 5.2.
**Transcript 5.2. Introducing the Knowledge and Knowing Study (Class 4C, Week 1, Day 1)**

<table>
<thead>
<tr>
<th>Tn</th>
<th>Speaker</th>
<th>Transcript</th>
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<tbody>
<tr>
<td>1</td>
<td>Mr. Archer</td>
<td>Now, Okay, could I have eyes on me please? Luke? Luke? Now, in the Scientific Thinker Project the thing we’re going to be doing the most research on, we’re going to be researching a few things, but the thing we’re going to talk about all three weeks that we’re doing it is about what we know and why we think we know it. Because all day everyday we talk about—I really need people to focus on me (snaps fingers). I need to make sure the notebooks aren’t a distraction. (Students put their notebooks down.) All day every day we hear people say they know things. And we ourselves say things that are sure—that we’re sure about, but what we want to do as researchers and scientists is we want to look at that. We want to look at how do you know what you know, how are you sure something is true, do you believe everything everybody says. Okay, now what we want to find out is, how do you know when to believe somebody and when not to believe somebody? And how do you, how do you determine when something is true and when something is not true? So, as researchers that’s what we’re going to do what are you thinking. Thomas?</td>
</tr>
<tr>
<td>2</td>
<td>Thomas</td>
<td>Like, because, like, sometimes, like, like, I know it’s, like, a lie because, like, it’s, like, the way they say it.</td>
</tr>
<tr>
<td>3</td>
<td>Mr. Archer</td>
<td>Hmmm.</td>
</tr>
<tr>
<td>4</td>
<td>Thomas</td>
<td>And the way the face looks, like, ’cause it’s like they say, an expression really not like they’re, like, they always start with, “Did you know?”</td>
</tr>
<tr>
<td>5</td>
<td>Mr. Archer</td>
<td>Okay, so, sometimes you can tell not to believe something by the way they say it. How else do you tell? How do you know when to think about something or believe something? Sarah.</td>
</tr>
<tr>
<td>6</td>
<td>Sarah</td>
<td>Like, um, when you (inaudible) when you’re done asking a question and, like, if I glance over and see them talking, like, suspiciously with some other people.</td>
</tr>
<tr>
<td>7</td>
<td>Mr. Archer</td>
<td>When people look suspicious about something. Okay. Erin?</td>
</tr>
<tr>
<td>8</td>
<td>Erin</td>
<td>By their face when they say it.</td>
</tr>
<tr>
<td>9</td>
<td>Mr. Archer</td>
<td>By their face. You can tell a lot by how they look.</td>
</tr>
<tr>
<td>10</td>
<td>Liang</td>
<td>How they act.</td>
</tr>
</tbody>
</table>
CHAPTER 5

Transcript 5.2. (Continued)

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<tr>
<th>Tn</th>
<th>Speaker</th>
<th>Transcript</th>
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<tbody>
<tr>
<td>11</td>
<td>Mr. Archer</td>
<td>How they act. Okay. So, that’s—that’s one way to find the information isn’t it, from somebody. Let’s break this down a little bit. What types of things do we say we know? What are some things that we know? What is something we say we know? What’s something you’re pretty sure you know?</td>
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</table>

((Over the next 2 minutes, Mr. Archer recorded 14 comments from 11 students including that they know: my name; I have five fingers on my hand; dinosaurs is real; jaguars are the best climbers; piranha plants only grow in deserts; trees give oxygen; you should always recycle; trees could be made into paper; shark is long as a bus; sharks have more teeth than people; my birthday is May 30; a cheetah is the fastest animal ever; Luke is real; and numbers don’t lie.))

| 12 | Mr. Archer  | Okay. All right. Now, before we go to the next part of our chart, looking at all these things that people say, like (pointing to the chart): I know my name is my name, I know that I have five fingers on my hands, I know dinosaurs are real, I know jaguars are the best climbers, that piranha plants grow in deserts, that you should recycle. How? Why do you believe those things? Why are you sure that those things are real? You said, “I know this is true.” “I’m sure that it is sure that it is sure that it is sure.” How do you know? |

((Over the next 7 minutes Mr. Archer generated a second list of sources students claimed they learn from (i.e., how they came to know what they know) including: you can check it, see it, experiment it, check in a dictionary, check in the Internet, from teachers, from books, TV, scientists, documents, parents, inference (use your knowledge to figure things out), and by asking questions.).)

| 13 | Mr. Archer  | Maria is ready. Okay, this is what we’re going to do. We are going to investigate what we know and why we think we know it. You’re going to ask these three questions and you’re going to copy them in your notebook. Not yet! Ms. Jasmine is going to interview me. Okay, are you ready? Now, she’s the scientist and I am the person she’s investigating. All right. So, she’s going to ask me these three questions and then she’s going to write the answers underneath them this is what you’re going to be doing, too. Go for it, Ms. Jasmine. |
Next, teachers explained to students that when each RA explained how they came to know the claim, why they think it’s true, or how they would convince someone of its truth value, the RA created evidence. Then they wrote the word evidence above the corresponding interview columns on the class chart. The teachers commented that people use all kinds of information, facts, and observations to support their claims just as the students did the previous day as well as the RAs they interviewed for homework. Students were asked to create a definition of evidence based on the examples generated by the class from the recorded RA responses. Teachers consolidated their answers and generated the definition: “Evidence is created when we use information, facts, observations and other tools to support or challenge our claim or someone else’s claim.” A sample of completed classroom charts for the term evidence is shown in Figure 5.2.

Analyzing the Claims and Evidence in Texts and Interviews

Armed with these definitions and examples of claim and evidence, we asked teachers to turn students’ attention to a separate but related investigation of the nonfiction texts they were reading during the block of instructional time dedicated to literacy lessons. The first text-based research questions we introduced were:
Teachers began with a whole-class reading and coding session using a nonfiction article and the KKS–Coding Sources Protocol (KKS-CSP). An example of a portion of coded text is provided to illustrate the outcome of this joint activity (Figure 5.3).

Figure 5.3. An example of a coded article (Gottier, 2009) using the Knowledge and Knowing Study–Coding Sources Protocol (KKS-CSP)
After the whole-class modeling sessions, it took an additional two days of reading in small groups with a teacher for the students to become comfortable identifying claims and evidence in their texts. By then, most were able to identify claims and evidence on their own and hold conversations with each other in small reading groups.

During this process, we noticed teachers and students invented distinct strategies to determine whether to code a statement as a claim or evidence. For coding claims, they developed the following questions: “Is the author saying this as if it is true?” “They are not telling us why/how …” and “Do we know this for sure?” For coding evidence they asked: “Did the author(s) prove their claim?” “Is an alternative possible?” “How do they know that?” “Are there any other clues on the page (pictures, drawings, illustrations)?” These strategies quickly became norms that facilitated analysis and aided teaching and learning.

In one class, third-grade teachers Levine and Fischer wanted to point out that writers who do not provide evidence could be considered untrustworthy. After the students read a sample text together and identified as many claim–evidence conjectures as they could, the teachers asked their class what they noticed about the article overall (Transcript 5.3). Sanjib explained the text had only claims and no evidence (turn 4). The teachers used this as an opportunity to challenge the text and asked the students, “Do we know if this is really true?”—where “this” referred to all the claims made in the text (turn 5)—and followed up by introducing the idea of trust: “Do we know if we could trust the person who wrote this?” (turn 7). They concluded with the rule that students shouldn’t trust an author who uses only claims and no evidence.

Transcript 5.3: Students explained that books with inadequate evidence may not be trustworthy (Class 3A, Week 1, Day 2)

<table>
<thead>
<tr>
<th>Tn</th>
<th>Speaker</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ms. Levine</td>
<td>That’s right, there’s no evidence, Malique. So what do you notice about this whole article?</td>
</tr>
<tr>
<td>2</td>
<td>Students</td>
<td>((Hands raised in bids to be called.))</td>
</tr>
<tr>
<td>3</td>
<td>Ms. Levine</td>
<td>So what did you notice?</td>
</tr>
<tr>
<td>4</td>
<td>Sanjib</td>
<td>There’s only claims.</td>
</tr>
<tr>
<td>5</td>
<td>Ms. Levine</td>
<td>There’s only claims. Do we know if this is really true?</td>
</tr>
<tr>
<td>6</td>
<td>Students</td>
<td>((Choral response.)) No.</td>
</tr>
<tr>
<td>7</td>
<td>Ms. Levine</td>
<td>Do we know if we could trust the person who wrote this? Why—</td>
</tr>
<tr>
<td>8</td>
<td>Ms. Fischer</td>
<td>Why would we trust them or why wouldn’t we trust them?</td>
</tr>
<tr>
<td>9</td>
<td>Nichole</td>
<td>Because there’s only claims and no evidence.</td>
</tr>
<tr>
<td>10</td>
<td>Ms. Levine</td>
<td>Because there is only claims and no evidence.</td>
</tr>
</tbody>
</table>
We understand why the teachers wanted to connect trustworthiness with evidence production and we even encouraged this discussion, but later we wondered whether that particular oversimplification might err on the side of another type of single-mindedness. While Ms. Fischer and Ms. Levine attempted to help students avoid one extreme—believing everything they read (gullibility)—we didn’t want to foster the other extreme—doubting everything they read (skepticism). We were aiming for a balanced position that recognized many possible realities. For example, even without evidence we might still trust an author’s claim(s) because we have some reason to think she or he is trustworthy (perhaps the author is the person who did the investigation), but we must also make a note that the lack of evidence is troubling. We might want to seek out other sources or test out the claims ourselves before we accept them.

In another third-grade class, Ms. Cheney solicited students’ opinions about whether they should trust the claims of an author who does not provide supporting evidence (or address challenging evidence) for her/his claims (Transcript 5.4). Here students suggested more nuanced positions, which were in keeping with those we were seeking to help them develop: (1) a little proof is enough to earn trust (Turn 14, Mason and turn 24, Lindsay); (2) I’m more likely to trust if the evidence is strong (turn 16, Nadia); (3) the authors are scientists and that is a trustworthy source (turn 18, Tommy); (4) they still may be studying and gathering the convincing evidence, so I’ll believe them for now, but I’d like to see the evidence eventually (turn 20, Katie).

Ms. Cheney remained agnostic while she encouraged students to share whether they trusted authors who “made so many claims and not that much evidence.” In response, students shared a range of opinions, which could be investigated further. As we observed and worked with our teacher-researcher partners, we found nearly every conversation they initiated with students, no matter how simple on the surface, yielded responses and ideas worthy of further inspection or research. We concluded that the learning tasks and research questions featured in the KKS were promoting and supporting rich, student-led investigations teachers felt comfortable mediating.

Analyzing the Sources of Claim and Evidence Commonly Used in Texts and Interviews

After introducing the concepts of claim and evidence (i.e., the tools for re/production in most science-related knowledge-acts), we asked teachers to have students analyze the responses from their interview protocols (and nonfiction texts) in as many ways as possible. One measure was to have students consider the answers to the question, “How did you come to know that claim about___?” When asked to name all the sources they and their RAs used in knowledge-acts such as claim–evidence conjectures, they generated a pretty comprehensive list. Each class list included a subset of the sources shown on Table 5.1 and a corresponding two- or three-letter code for each source.
Transcript 5.4. Students provided reasons for trusting or not trusting an author who provides more claims than evidence (Class 3C, Week 1, Day 2)

<table>
<thead>
<tr>
<th>N</th>
<th>Speaker</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ms. Cheney</td>
<td>Tommy says it’s another claim and he is right [claim 6]. Guys! So, do we see more claims or do we see more evidence?</td>
</tr>
<tr>
<td>2</td>
<td>Students</td>
<td><em>(In unison.)</em> Claimsss.</td>
</tr>
<tr>
<td>3</td>
<td>Ms. Cheney</td>
<td>Do … do we, I mean, does that make you question the author?</td>
</tr>
<tr>
<td>4</td>
<td>Students</td>
<td>Yes.</td>
</tr>
<tr>
<td>5</td>
<td>Ms. Cheney</td>
<td>You see so many claims. Does that make you think like, “Wait, can I trust the author?” Do you still trust him even though he made so many claims?</td>
</tr>
<tr>
<td>6</td>
<td>Students</td>
<td><em>(Several students talking at once.)</em> Yes. No.</td>
</tr>
<tr>
<td>7</td>
<td>Ms. Cheney</td>
<td>Someone, raise your hand and let me know.</td>
</tr>
<tr>
<td>8</td>
<td>Nadia</td>
<td><em>(Only student to raise a hand.)</em></td>
</tr>
<tr>
<td>9</td>
<td>Ms. Cheney</td>
<td>Raise your hand. Not a lot of you—do you still trust the author? There’s no right or wrong answers, so I’m going to start calling on people.</td>
</tr>
<tr>
<td>10</td>
<td>Students</td>
<td><em>(More students raise their hands.)</em></td>
</tr>
<tr>
<td>11</td>
<td>Ms. Cheney</td>
<td>Mason, do you still trust the author, even though he made so many claims and not that much evidence?</td>
</tr>
<tr>
<td>12</td>
<td>Mason</td>
<td>Mmm, yes?</td>
</tr>
<tr>
<td>13</td>
<td>Ms. Cheney</td>
<td>How come?</td>
</tr>
<tr>
<td>14</td>
<td>Mason</td>
<td>Because, I think as long as he gives evidence it still proof.</td>
</tr>
<tr>
<td>15</td>
<td>Ms. Cheney</td>
<td>You’re saying as long as he still gives a little evidence he’s trustworthy? Who says, “No, no I don’t believe, I don’t trust the author”? Nadia.</td>
</tr>
<tr>
<td>16</td>
<td>Nadia</td>
<td>I don’t trust the author because he made a lot of claims and so many and so little evidence.</td>
</tr>
<tr>
<td>17</td>
<td>Ms. Cheney</td>
<td>So, you’re thinking that. “You talk a lot of talk but you don’t prove anything. I need proof I need solid proof for me to trust you.” Okay, that’s a good point. Tommy.</td>
</tr>
<tr>
<td>18</td>
<td>Tommy</td>
<td>But it says—but, scientists, so I think it is real.</td>
</tr>
<tr>
<td>19</td>
<td>Ms. Cheney</td>
<td>Okay, okay, so there is some evidence, like, he’s making a lot of claims, but not always giving evidence. Katie.</td>
</tr>
<tr>
<td>20</td>
<td>Katie</td>
<td>I still trust them because scientists are still—they’re probably still studying about what they’re writing.</td>
</tr>
<tr>
<td>21</td>
<td>Ms. Cheney</td>
<td>Okay. Lindsay.</td>
</tr>
<tr>
<td>22</td>
<td>Lindsay</td>
<td>I trust the author.</td>
</tr>
</tbody>
</table>
Table 5.1. Sources of evidence for claims generated by students in participating third- and fourth-grade classes

<table>
<thead>
<tr>
<th>Sources of tools for thinking and knowledge-acts (claims and evidence)</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal experience or real-life experience: I tried it, I watched, I listened, I saw/noticed</td>
<td>PE or RLE</td>
</tr>
<tr>
<td>Saw it on TV—news, nature program, cartoon, show, etc.</td>
<td>TV</td>
</tr>
<tr>
<td>Saw it in a movie</td>
<td>MOV</td>
</tr>
<tr>
<td>Read it in a book</td>
<td>BK</td>
</tr>
<tr>
<td>Read/saw/heard it on the Internet</td>
<td>WWW</td>
</tr>
<tr>
<td>Heard it from a relative, teacher or friend (other people)</td>
<td>RTF or OP</td>
</tr>
<tr>
<td>Read, heard, saw it, but don’t remember where</td>
<td>READ</td>
</tr>
<tr>
<td>It just makes sense or sounds right</td>
<td>IJK</td>
</tr>
<tr>
<td>Learned it in school</td>
<td>PS</td>
</tr>
<tr>
<td>Tested it myself</td>
<td>TT</td>
</tr>
<tr>
<td>Experiments (someone did an experiment)</td>
<td>EXP</td>
</tr>
<tr>
<td>Video games</td>
<td>VG</td>
</tr>
<tr>
<td>Prior knowledge</td>
<td>PK</td>
</tr>
<tr>
<td>Museum or other places</td>
<td>MUS or PL</td>
</tr>
<tr>
<td>Advertisements</td>
<td>ADS</td>
</tr>
</tbody>
</table>

After listing all the sources they noticed and generating codes for each, students used the codes to categorize and mathematize (i.e., code and analyze) their interview data. For example, if an RA said they learned dinosaurs are big from a book, then the interviewer coded the response BK for evidence from a book used to support the claim (see Figure 5.4 for an example of student work).
<table>
<thead>
<tr>
<th>Claim</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who did you interview?</td>
<td>(1) Please tell me something you know about sound.</td>
</tr>
<tr>
<td>My sister</td>
<td>because I heard many kind of sound</td>
</tr>
<tr>
<td>My sister</td>
<td>I know that some sounds come from animals</td>
</tr>
</tbody>
</table>

Figure 5.4. A student-coded interview using the KKS-CSP
Figure 5.5. Examples of tally posters after students coded the RA responses in their interviews.
After coding their interviews and consulting with a peer or teacher on their categorizations, interviewers were asked to tally up the number of times each source type was used. The teachers then reassembled the students as a group and helped them tally the responses from all the RAs so the students could see whether there were any trends in the type of sources used by the RAs in their community.

Possible questions for analysis included, but were not limited to:

- How many times did our group of RAs use each source type?
- Which source type did most RAs use?
- Any ideas why the RAs we interviewed used this source type most often?
- Any ideas for how we could find out why this group of RAs we interviewed uses this source type most often?
- Can we say all the RAs or all people in the world use this source type the most?
- Which source type was used the least?
- Any ideas why the RAs we interviewed used this source type the least?
- Any ideas for how we could find out why this group of RAs we interviewed uses this source type the least?
- Can we say all RAs or all people in the world use this source type the least?
- How does our summary of the whole group compare to what individual people say they do?

Most of the teacher-researcher collaborators in the study asked students to reflect on which sources were used the most, which the least, and why students thought each of these two trends might be the case. For example, Ms. Fischer and Levine’s class found the most popular source of evidence from their sample of RAs was “Real-life Experience.” When students were asked why they thought so many people used real-life experiences as their source of evidence for their claims about sound, they explained (1) because sound is like real life, (2) because we hear sound everywhere, and (3) almost everything makes sound. The teachers followed up each answer with clarifying questions and tested each student explanation against real-world examples, which modeled a process of providing supporting evidence for each student’s idea. (One of these follow-up exchanges is shown in Transcript 5.5.) We noticed our teacher partners did not pose the suggested research questions, and as a result students did not examine their own conclusions more critically, consider alternative explanations, or examine how generalizable the findings actually were (or were not).

We recommend lingering over the data and asking as many questions as possible (at least ask those we have listed above), because interpreting and drawing conclusions is one of the most important knowledge-acts of science. It is during this process tools for thinking are created, challenged, revised, discarded, and reproduced. Treating the tally as an outcome that confirms our current belief negates the point of the investigation and the effort expended to design and conduct it. When they chose not to have students test their explanations with further research, our teacher-researcher partners may have inadvertently reinforced a generalization that may not be true.
Although none of the teachers explored what we believe are some of the most important questions of this type of research project (e.g., Can we say all RAs or all people in the world use this source type the most/least? How does our summary of the whole group compare to what individual people say they do?), Mr. Archer did challenge his students’ assumptions in a remarkable way. After tallying the results of their analysis of interviews, Class 4C found their RAs primarily used books and other people as sources of evidence to support their knowledge claims. In this excerpt (Transcript 5.6), Mr. Archer compared students’ expectations of themselves with the practices they expected among authors with respect to evidence presentation.

In this exchange, Mr. Archer pointed out students were inconsistent with their expectations. On the one hand, they and their RAs claimed they were satisfied with evidence that comes from their own personal experience, books, or other people when they adopted a knowledge claim and made it their own, but they had much higher expectations for authors who provided evidence for claims. They expected authors to describe experiments or investigations in support of their claims. In the first turn, Mr. Archer asked, “If you are reading an article and somebody uses a source to prove their claim, which source would you want them to use the most?” When a student replied “books,” Mr. Archer was incredulous and challenged the
Transcript 5.6. Teacher questions RA's preference for testimony of other people over other sources of evidence about claims (Class 4C, Week 1, Day 3)

<table>
<thead>
<tr>
<th>Trn</th>
<th>Speaker</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mr. Archer</td>
<td>Now, if you are reading an article and somebody uses a source to prove their claim, which source would you want them to use the most? Which source would you want them to use the most? If they said, “Dinosaurs do this and here’s my evidence,” what source would you want them to use?</td>
</tr>
<tr>
<td>2</td>
<td>Liang</td>
<td>Um, books.</td>
</tr>
<tr>
<td>3</td>
<td>Mr. Archer</td>
<td>Okay, that they read that? That they read in a book? That’s what you’d want them to use? Do you want them to say “We read it in a book that skulls have rough areas on them”?</td>
</tr>
<tr>
<td>4</td>
<td>Students</td>
<td>No!</td>
</tr>
<tr>
<td>5</td>
<td>Mr. Archer</td>
<td>Do you want the article to tell you that they went on the Internet and looked for it?</td>
</tr>
<tr>
<td>6</td>
<td>Liang</td>
<td>No, the fossils!</td>
</tr>
<tr>
<td>7</td>
<td>Mr. Archer</td>
<td>Okay, so what would that be?</td>
</tr>
<tr>
<td>8</td>
<td>Students</td>
<td>((Overlapping talk.)) Books? No! To see!</td>
</tr>
<tr>
<td>9</td>
<td>Mr. Archer</td>
<td>((Prompting students.)) To see or maybe …</td>
</tr>
<tr>
<td>10</td>
<td>Students</td>
<td>Test it, experiment.</td>
</tr>
<tr>
<td>11</td>
<td>Mr. Archer</td>
<td>Experiment, test it. Okay. What else would you want? What else would you want?</td>
</tr>
<tr>
<td>12</td>
<td>Jackie</td>
<td>Places.</td>
</tr>
<tr>
<td>13</td>
<td>Mr. Archer</td>
<td>Okay, that they went somewhere to see it, okay. Now, the ones that you would want, you would want them to do an experiment, right? Or to see it or to go to it. How many of us use those sources? Do we use very many of those sources?</td>
</tr>
<tr>
<td>14</td>
<td>Students</td>
<td>No.</td>
</tr>
<tr>
<td>15</td>
<td>Mr. Archer</td>
<td>Did we use very many of those sources?</td>
</tr>
<tr>
<td>16</td>
<td>Students</td>
<td>No.</td>
</tr>
<tr>
<td>17</td>
<td>Mr. Archer</td>
<td>No. If you are reading a book and they made a claim, what source would you not want them to be using? What source would make you go, “I don’t believe you.”</td>
</tr>
<tr>
<td>18</td>
<td>Jon</td>
<td>People.</td>
</tr>
<tr>
<td>19</td>
<td>Mr. Archer</td>
<td>If they ask somebody, right? Would you believe them if they gave a person?</td>
</tr>
<tr>
<td>20</td>
<td>Students</td>
<td>No.</td>
</tr>
</tbody>
</table>

(Continued)
students with the proposition, “Do you want them to say, ‘We read it in a book that skulls have rough areas on them?’” The students disagreed and explained they expected the author to discuss tests or experiments done by someone (if not themselves). Mr. Archer then asked whether the students would believe authors who said they know what they know because they read it on the Internet, in a book, or asked another person. The students grew animated and replied they wouldn’t believe authors who supported their claims this way. At this point, Mr. Archer directed their attention to the class data set (Figure 5.6) and challenged them, “But you guys use that a lot!” (turn 23).

By highlighting the contradictory nature of students’ expectations for authors and for themselves Mr. Archer had begun to establish two new norms in his classroom: (1) We will maintain consistent and high expectations for claim–evidence relationships and (2) the strongest claim–evidence relationships are derived from experimentation.
or investigation. The first norm refers to the practical action students are expected to take—namely, they should be consistent in their criteria for judging claim–evidence relationships. The second norm refers to an empiricist norm, where sense data (e.g., seeing, touching, hearing, smelling, tasting) are given privileged status over other forms of evidence.

Although Mr. Archer’s approach may resonate with us as science educators, we advise caution. The point we are trying to make in the BBST framework for science education is that, as we engage ourselves and our students in examinations of how they (and others) came to know what they know, we must make an effort to document as many ways of knowing as possible and keep them all problematic in our research. At no point in a student’s education do we want to encourage using student research to claim there is one correct way of knowing.

Research Team Formation

After the whole-class analysis session, most students were ready to set up new research projects to find answers to questions that interested them. For example, they could conduct another interview to find out what sources their RAs preferred to use to learn new things. They could investigate how RAs decide what information is true or trustworthy or how many book authors in the classroom library provided evidence for their claims. A number of student interviewers were interested in recording their experiences and feelings as they interviewed an RA and were encouraged to research the reports of other interviewers.

Students (working alone or together in small groups) designed interview questions and research program plans and carried them out as homework or in class depending on the teacher. We recommended that students analyze their findings and review them with a small research team before presenting their research findings to the class within a week of conducting the work. The point was to establish a community that supported the research process, not only by providing tools for data gathering and analysis (e.g., interview protocols, research questions), but also by providing feedback on possible findings and new directions.

Reflecting on Decision Making

In another whole-class study, we asked students to investigate the knowledge-acts of decision-making using the KKS-Decision Protocol (KKS-DP). After students were asked to agree, disagree, or remain undecided about a particular claim-tool, the whole class analyzed the sources of evidence used for decision making and discussed the implications of using these sources. To illustrate how we worked with teacher-researchers to accomplish this, we have provided the relevant pages from the project’s teacher manual in Box 5.2.
Box 5.2

Decision Study—Excerpt from the Scientific Thinker Project Teacher Manual

In the lessons so far, students have begun conducting their own research on evidence and how people create evidence to support their claims. They’ve explored how author(s) sometimes use evidence to support their claims and how often authors just provide claims without evidence. They’ve investigated what sources people use as evidence to support their own claims through interviews of RAs at school and at home. They’ve started asking why people prefer to use some sources instead of others and why they feel sure or not sure about things they know. These will be continued throughout the unit on claims and evidence. The purpose of the lesson is to broaden our view to include evaluating evidence and asking: When do we need evidence? How do we decide that we need evidence? How do we decide when to believe what someone else says? How do we decide that our own activity/observations/research is good evidence for a claim? How do we decide what is good evidence? How do we test claims and evidence stated by others and ourselves? How do we decide when we have enough evidence? What do we do when we are unsure or we disagree with a claim or evidence for a claim?

One way to begin this discussion is to have students make a decision (agree or disagree) about a particular claim and then reflect on: (1) their decision-making strategy, (2) their confidence (how sure they are), and (3) what types of new information could make them change their mind.

1. Making Decisions

To initiate the discussion, display a chart with one of the claims reported by an RA and ask students to decide whether they agree or disagree with the claim or if they are undecided.

Sample chart

<table>
<thead>
<tr>
<th>CLAIM: Dogs don’t drink milk.</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVIDENCE: When given milk my dog ran away. Aisha’s brother read a book that said dogs don’t drink milk. Anita tried it on her cousin’s dog.</td>
</tr>
<tr>
<td>Why I disagree</td>
</tr>
</tbody>
</table>

Questions

Have students write their decision (disagree, agree, undecided) and their reasons on a sticky note.

(Continued)
2. Reflecting on decision making

Post student responses and randomly select up to three students in each category (disagree, undecided, and agree) to share why they agree, why they disagree, or why they are unable to decide. Record their responses on the new chart. If they have any questions, record their questions, too.

**Sample chart**

<table>
<thead>
<tr>
<th>Why I agree</th>
<th>Why I am undecided</th>
<th>Why I disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>My dog drinks a lot of water.</td>
<td>I heard that dogs drink milk and that they don’t drink milk.</td>
<td>I gave a dog milk and he drank all of it.</td>
</tr>
<tr>
<td>I asked the guardian if dogs drink milk and he said no.</td>
<td>My uncle has a dog that drinks milk and water.</td>
<td>I gave a dog a choice of milk or water and it drank the milk.</td>
</tr>
<tr>
<td>My cousin has a dog with milk in his cage and when he gets out he goes to drink water.</td>
<td>I could be the dog’s just not thirsty.</td>
<td>I gave my dogs milk and they drank it.</td>
</tr>
</tbody>
</table>

**Questions**

*Do dogs drink milk because they’re mammals?*
*Maybe some dogs drink milk and some don’t?*
*Maybe big dogs don’t drink milk and puppies do?*

Ask the class to code all the sources in the responses as they did when they coded the interview responses earlier in the week. What sources of information did the students who shared use for their decision making? Did they use their own experience or that of others? (Label each according to the class codes, e.g., PE, BK, MOV, TV, WWW, etc.)

3. Homework—changing decisions

For homework, ask the students to look over the claims from the first set of interviews (compiled on a handout) and pick one they agree with, one they disagree with, and one they are undecided about. Ask them to describe information that they think would make them change their mind about their decision. For example, if they decided they did not agree, they should give the information that would cause them to either change their mind to one of the alternative positions, “I disagree,” or to “I’m undecided.”
Again, the protocol was designed to help teachers learn more about the sources students use to make decisions about information, but it was also designed to provide a tool for students to conduct more systematic analysis and reflection on their learning and knowledge-acts. The aim was not to rank particular sources in a hierarchy of value, such as what happened when class 4C began to develop the idea experiments and testing are preferable to hearsay. Through these exercises we were trying to establish the norms or habits of considering alternative explanations, and to focus on what is being said and the evidence for it, rather than who is saying it.

**Unexpected Benefits of the Knowing and Knowledge Study on ELA Test Preparation**

During a group interview with teacher-researcher collaborators in the second year of the development and testing of the instructional materials described here, Sue asked the group of teacher collaborators about their impressions of materials and would consider using them again. One of the teachers responded that, after teaching students how to identify claim–evidence conjectures in informational texts, it was much easier to teach children how to write persuasive essays. Others agreed and explained that, when they were reviewing drafts of student writing and needed to provide feedback, now all they had to say was “I understand the point you are trying to make, but where is your evidence? You claimed this, but I don’t see your evidence for it. What type of evidence do you think would convince your reader of your position?” In other words, the elements of the persuasive essay now made sense to students. Teachers could spend more time on helping their students improve the quality of the content of their student’s essays because they no longer had to spend time re-explaining the mechanics of the genre.

**ESTABLISHING STUDENT-CENTERED RESEARCH ACTIVITIES IN DAILY INSTRUCTION WITH THE KKS STUDY**

After the initial development and research cycles were complete, Michele began exploring how to integrate the various tools into her and students’ daily practice. She felt once a study of claim and evidence conjectures was underway in her classroom, students’ understanding of these tools for thinking could be used to structure science learning for any new tool (e.g., energy chains, life cycles, adaptations).

**Using the KKS–IP as a New Type of Formative Assessment**

When Michele began to use these instructional materials with her students (grades K–3) she noticed two possible uses for the KKS-IP. The first use was its intended purpose: to empower students to research their own learning and development. By giving students the opportunities to witness and find out how they and their RAs learn,
she found students realized learning and development are something they control; learning and development are not processes that happen to them. By studying the production and reproduction (herein, re/production) of tools for thinking (i.e., how people come to know what they know or knowledge-acts) she noticed students tested out and grew their own ideas, gained confidence in their ability to explain how they know what they know, and expanded their curiosity about alternatives or doubts.

The second use Michele discovered for the KKS-IP was as a formative assessment tool. It is common for teacher educators and professional developers to teach us the importance of using a variety of formative assessments such as KWL charts, KLEW charts, Accountable Talk, and structured probes to uncover students’ prior knowledge before starting a new instructional unit or as tools to start conversations with students. All these pedagogical strategies aim to make instruction more student-centered, help teachers listen to what students say, and ensure they have opportunities to talk. Yet in our experience, when these tools are used they effectively close off conversation by seeking out simple, short answers from students and leave teachers with little data for improving instruction. We find these formative assessments can take a significant investment of instructional time without a clear payoff for teachers or students. In the next section, we compare various formative assessments and propose that the KKS-IP is a powerful alternative to add to our instructional toolbox.

**Comparison of the KKS-IP with Other Tools and Methods**

Graphic organizers such as KWL charts and KLEW charts are organizers of learning goals and achievements. They are typically used to monitor and track student responses at discrete periods over time starting with the beginning of the unit (as a pre-assessment) and following through to the end of the unit (as a post-assessment) in order to provide evidence of student learning.

**KWL chart.** The KWL chart is a three-column graphic organizer teachers use to record (1) what children know about a topic before reading more about it (K); (2) what a child wants to know or find out about the featured topic considering what they already know before reading (W); and (3) what the children learned and still need to learn about the topic after reading an expository text (L) (see Figure 5.6 for an example of a completed chart).

The KWL graphic organizer was designed by Donna Ogle (1986) as a teaching procedure to “help teachers become more responsive to students' [prior] knowledge and interests when reading expository material, and model for student[s] the active thinking involved in reading for information” (p. 564). The design was based on a prevailing assumption, at the time, that prior knowledge influences how we interpret what we read and what we learn from reading. Although educational researchers such as Richard Anderson and James Pichert (1978) and John Bransford (1983) agreed
and argued reading comprehension depends on our ability to access the knowledge we already have about the topic, classroom studies suggested most teachers were not eliciting children’s background knowledge during reading instruction. Ogle designed the KWL chart to alleviate this problem.

Ogle’s original instructions were to begin with a brainstorming session to learn what a group of students knows about a topic before reading and to “activate whatever knowledge or structures the readers have that will help them interpret what they read” (Ogle, 1986, p. 365). This is usually how teachers explain the purpose of the first column. In fact, on the Teaching Strategies page of the National Education Association website teachers are instructed to initiate and record the brainstorming session and encourage students to explain their associations, especially when they are vague or minimal, with the prompt: “What made you think of that?”

This was not, however, the complete instruction given by Ogle. In her article, teachers were instructed to “record whatever the students volunteer about the topic” (Ogle, 1986, p. 565) because it is through this process of helping students put their “bits of memory into order” that teachers could be able to help students discover what they don’t know about the topic. She explained this would also help foreshadow the second column of the chart, “What do I want to learn or find out?” Therefore, not only was the purpose of the brainstorming to uncover the associations students make, it was also to encourage them to question what they think they know and what they realize they do not know. Ogle went on to suggest that, after the original brainstorming was complete and the student responses were recorded, teachers

<table>
<thead>
<tr>
<th>What we know about sound</th>
<th>What we want to know about sound</th>
<th>What we learned about sound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sounds are everywhere.</td>
<td>What is sound?</td>
<td>Vibrating objects make sound unless they are in a vacuum.</td>
</tr>
<tr>
<td>There are many kinds of sounds.</td>
<td>What is the loudest sound ever made?</td>
<td>We did not find an answer to this question.</td>
</tr>
<tr>
<td>Sounds make vibrations.</td>
<td>Can dogs hear sounds we can’t hear?</td>
<td>Yes, most dogs can hear higher pitched or “frequency” sounds than humans.</td>
</tr>
<tr>
<td>Sound comes from your ear.</td>
<td>How does sound travel from upstairs to downstairs in my house?</td>
<td>Sound travels through solids, liquids, and gases.</td>
</tr>
</tbody>
</table>

Figure 5.6. An example of a completed KWL chart
should not simply accept the statements students offered, but probe them further to make them think about the sources and substance of their suggestions with questions such as: “Where did you learn that?” or “How could you prove that?” (Ogle, 1986, p. 566). She argued that extended questioning like this “helps other students feel freer to provide contradictory pieces of information that can then be confirmed through the reading” (Ogle, 1986, p. 566).

It is our experience that this advice from Ogle’s original article has been lost in translation, to the point where the procedure is not integrated as she intended in teacher preparation or professional development sessions, nor is it represented completely in online summaries and guides recommend the use of KWL charts. In fact, we were unaware of her work and her rationale until we tracked down the history of this pedagogical procedure for this book! We highly recommend reading her original (well-written) article in *The Reading Teacher* (February 1986), especially if you are a KWL chart user.

There is a second element to completing the “What do I know” column on Ogle’s KWL chart that we believe has been completely omitted from practice (if it was ever adequately integrated), and is reminiscent of our goal of putting students in the position of analyzing their own data. Ogle explained once the list of what students know about a topic is recorded students should then analyze that list and create categories of information (i.e., identify themes). She recommended the prompt, “Before we read this article on sea turtles, let’s think awhile about what kinds of information are most likely to be included. Look at this list of things we already know: Do some of them fit together to form a general category of information?” (Ogle, 1986, p. 566). She also recognized it could be challenging at first for students and teachers to do this and recommended teachers model a few examples to help students understand the task. For example, one way to categorize students’ knowledge about sea turtles is to point out several pieces of information that describe how turtles look; so one category of information might be “Description.” Other categories might include: life cycle, adaptations, eating habits (feeding/prey), enemies (predators), form and function, reproduction, care and nurture of young, health, habitat, and ecosystem. These should look familiar because they are typical topics or themes listed in science learning standards. They are also the ways career learner–scientists typically categorize their tools for thinking about living organisms. Ogle did not make as strong a case for why students should analyze their responses and learn to categorize this way, but we argued in Chapter 4 that this categorization process is one of the most important language games students being/becoming scientists need to learn. The ability to shift back and forth between themes that encapsulate the general principles governing living things (theoretical tools) and the specific context of observing a particular living thing (everyday tools) strengthens students’ positions as researchers by helping to make informational texts accessible and understandable, and fostering deeper and more interesting questions for further research and learning. These connections between everyday and theoretical tools for thinking in science are essential if students are to crystalize for themselves the language of science. Ogle
argued the brainstorming and analysis procedures could energize students and create
the instructional purpose for reading “to find answers to questions that will increase
their reservoir of knowledge on this topic.”

The entries in the second column, “What do we want to learn or find more
about?” should be the result of a whole-class discussion facilitated by the teacher,
who “highlights [students’] disagreements and gaps in information” (Ogle, 1986,
p. 566). Furthermore, the entries in this column should be found while completing
the “Know” column and should help the students raise questions to be answered.
Once the second column is complete and students are armed with the questions
they’d like to answer, they read the article and summarize, note, record, or otherwise
mark what they find. After checking in with the students periodically, the teacher
is instructed to help the class build a record of which questions the article helped
answer and which remain unclear (Column 3, “What we learned”). For the questions
that remain unanswered or unclear, Ogle suggested teachers have additional books
and articles about the topic ready for students to read and encourage them to “fulfill
their desires to know.”

One of the most puzzling prompts we often hear teachers ask struggling students
who cannot think of anything they want to learn about a particular topic is, “What
do you think you will learn about this topic from the text you will be reading?”
Nowhere is this prompt (commonly found in teacher education and professional
development materials) mentioned by Ogle. Furthermore, when we consider this
from a learner–scientist’s perspective, we might argue their rational response to such
a question should be, “How should I know, I haven’t read the text yet! Maybe the
author will answer our questions, maybe they won’t.” What is the point of having
a student predict what they will find in a text? A far more useful skill than mind
reading is for students to learn how to read with the purpose of answering a question.
This promotes a different type of reading—one that requires learning how to look
for category clues on the table of contents, in the index, or in subheadings, clues
that direct readers quickly to what the author has to say on a particular subtopic
(e.g., feeding) that might interest him or her (e.g., What do sea turtles eat?). Ogle
had it right; go back and read her original seven-page article. We always try to read
the original when we are given a tool and are tempted to use it mindlessly. If the
original is too difficult to understand, we seek help from that leader, professor, or
professional developer who directed us to use it; or we turn to the Internet and our
libraries (and librarians) for additional research—similar to the way we structured
our personal learning method (see Chapter 4).

At the core of Ogle’s design of the KWL procedure was the principle “readers need
to be in charge [of] their learning and actively pursue their own quest for knowledge”
(Ogle, 1986, p. 567). We couldn’t agree more. How did Ogle’s approach get stripped
of its original intention and history and become simply a graphic organizer? The
same way each scientific fact in the stockpile of scientific knowledge gets stripped
of its origins and purpose when we mindlessly accept an authority that tells us, “This
is the tool you use in this situation.” As you know by now, our first response should
not be to accept and blindly use it. Instead, our first response should be to ask the following questions: How did you come to know that? Why do you think it’s true? Who says we should use this tool? Where did that tool come from? Who invented it? What problem were they trying to solve with it? How does it propose to help my students learn? It is only through these types of investigations we can come to learn the intention of the developer and decide, with our students, whether it works and is reasonable.

*KWL chart limitations.* When we started writing this chapter, our initial notes about the KWL chart outlined a series of limitations. We present those next, but it is important to note these are not the limitations of Ogle’s KWL procedures; they are the limitations reflected in how the KWL chart is typically integrated into teaching practice.

First, most whom use KWL charts reinforce the view knowledge is a fixed, static object stored in our memory, or in a book, rather than something we do—a knowledge-act. Therefore, getting answers to questions is presented as a matching game—match the answer with the question. Furthermore, it reinforces the assumption that answers can be found, and are correct, and final. When answers are found, the questions are eliminated and the process continues with a new topic. Typically, texts are not questioned; they are only used as sources of answers.

Second, as the KWL chart is typically integrated into practice, teachers do not allow for any explanation or critique about what students claim to know. Because the chart is commonly used as a tool during whole-class discussion, if a student adds incorrect information to the KWL chart and goes unchallenged, then more students might accept the information without question. When this happens, it is up to the teacher to identify the misinformation once it has been documented and create an interactive group discussion that specifically asks the respondents to explain what they added to the KWL chart. If the teacher does not have this corrective group discussion, then letting the misinformation persist on the chart clouds the meaning, purpose, and validity of the chart. Given this reality, that a KWL chart must be monitored by the teacher, it is difficult to actually use this tool as a pre-assessment because the teacher would have contributed so many corrected ideas to the chart in the process of building it that it becomes less student developed and more teacher developed.

Third, students rarely understand the point of recording what they say they know, what they want to know, and what they learned. This student reaction means the exercise was ineffective. The purpose of the procedure is to help students see learning shouldn’t be framed around what an author chooses to include, but around what learners want to know and how they go about searching and locating texts that address their questions. With this purpose in mind, the KWL chart can be a useful teaching strategy, but this purpose is usually lost.

Fourth, it is rare for teachers to revisit the K column of the chart at the end of the unit to discover any information that has been found to be suspect through the unit
work. Neither does Ogle address this. The KWL entries are not viewed as data to be analyzed or ideas to be critiqued; they are collected in a moment in time, used briefly, and then discarded for the next reading topic and a fresh chart.

Fifth, the KWL chart is still a teacher-controlled tool for learning. It was designed to help the teacher elicit children’s background knowledge in order to inform instruction. The charting process is usually initiated by the teacher, recording is performed and filtered through the teacher’s perspective, the teacher nominates all the speakers, and the teacher controls participation in and pacing of the conversation. Even though it is meant to foster student agency it is easy for the learner to sit back and proceed mindlessly and passively—waiting for permission, waiting for instructions, waiting to be evaluated, waiting to be approved—blindly following.

KLEW chart. The KLEW chart is an adaptation of the KWL chart. It is a four-column graphic organizer teachers use to record (1) what children think they know about a topic before reading more about it or conducting some kind of hands-on investigation (K); (2) what the children are learning about the topic (L); (3) what evidence supports the learning previously described (E); and (4) what the children are still wondering about, after reading expository text (W). See Figure 5.7 for a complete KLEW chart.

<table>
<thead>
<tr>
<th>What we think we know about sound</th>
<th>What we learned about sound</th>
<th>What evidence we have for our learning</th>
<th>What we are still wondering about</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sounds are everywhere.</td>
<td>Sound is not in a vacuum.</td>
<td>Book and Internet video</td>
<td>Is space really a vacuum?</td>
</tr>
<tr>
<td>There are many kinds of sounds.</td>
<td>Pitch and volume are ways to describe sounds.</td>
<td>Book, teacher, and investigations.</td>
<td>How are there different voices like a cat, human, and dog?</td>
</tr>
<tr>
<td>Sounds make vibrations.</td>
<td>Vibrating objects make sounds unless they are in a vacuum.</td>
<td>Book and Internet video</td>
<td>Why?</td>
</tr>
<tr>
<td>Sound comes from your ear.</td>
<td>Our ears do not make sounds, they are receivers of sound.</td>
<td>Book, teacher, and model of ear</td>
<td>What other types of receivers do living things have, if they don’t have ears?</td>
</tr>
</tbody>
</table>

*Figure 5.7. An example of a completed KLEW chart*
This graphic organizer was designed by Kimber Hershberger, Carla Zembal-Saul, and Mary Starr (2006) to “highlight the essential features of inquiry”—observation and evidence (p. 50). Their goal was to align science instruction with the National Science Education Standards (National Research Council, 2000), by engaging children in scientifically oriented questions, having students give priority to evidence and the development of evidence-based explanations, and having students justify their proposed explanations. These authors did not cite Ogle’s original article; therefore their review of the purpose of a “traditional KWL chart” referred only to what is seen in practice rather than what could be achieved using Ogle’s original instructions. As a result of this omission, some of the authors’ modifications of the KWL chart are extensions of what Ogle intended, while other modifications change the purpose altogether.

For example, in the K column teachers are advised to “encourage students to share all their initial ideas, even though that might not be the ‘best’ scientific explanation” (Hershberger et al., 2006, p. 51). The emphasis on what they think they know “supports the idea that what students think they know can change as a result of the inquiry lessons” (Hershberger et al., 2006, p. 51). As with the approach used by most teachers the focus is on conceptual change—revealing students’ prior knowledge for the purpose of changing it if it is not the “best scientific explanation.” Ogle’s approach was focused more on empowering learners to take charge of their learning, to get “energized” by learning, and to question everything they knew. Ensuring conceptual change was achieved was not her major goal if we interpreted her original report as she intended.

Another major modification made by the KLEW authors was to transpose the W and the L columns. The structure of the chart drives investigations with a teacher-guided activity from which students test a given prediction. At the end of their tests, students are asked to make claims about what they know now, in conclusion. These are included in the L column. The original KWL was specifically designed for improving students reading comprehension, and student questions were seen as an important tool for learners to organize and control their own learning from the reading. Ogle clearly supported multiple rounds of reading, learning and wondering (e.g., K-W-L-W-L-W-L), so the transposition in the KLEW is really only influential on the first cycle.

The final major modification is the addition of the evidence column. This column is recorded at the same time as the findings from the investigations are recorded in the L column and arrows are drawn between the items in the two columns. In the KWL chart students offer the evidence from their readings as the L data, which should align with the question they are intended to answer. The major difference between KWL and KLEW is that evidence for learning comes from a book in the KWL method and from experimentation or empirical investigation in the KLEW method.

The KLEW authors found the questions students listed in the “Wondering” column emerged spontaneously, and students were motivated to construct more
evidence-based claims after further investigation. Also, because the questions were generated in the context of investigations, they were usually testable by the students, unlike questions from the KWL chart, which were more general and difficult to test.

The limitations of the KLEW are the same as for the KWL—it is a teacher-centered procedure and depends heavily on the teacher’s ability to maintain student interest in wondering and critiquing, albeit, perhaps, with less effort than for the KWL chart.

Accountable talk. Lauren Resnick, Sarah Michaels, and Mary O’Connor (2010) developed Accountable Talk as a structure to socialize students into the habit of reasoned discourse. An excerpt from one of their descriptions of the history and rationale for the development of Accountable Talk captures their perspective most clearly:

An occasional lesson—or even a semester’s course in “critical thinking” or “logical reasoning”—cannot produce the habits and practices of reasoned discourse. Reasoned discourse is a habit, a way of life. It must be socialized, learned by living daily for many months and years in an environment that expects such behavior, supports it, and rewards it in overt and subtle ways. The only venue in which there is any hope of achieving such widespread socialization is the school. To develop the “turn of mind” that privileges reasonable argument, discursive practice will have to permeate students’ school experience—every day and in all of the disciplines to which our schools are committed: science, mathematics, literature, history, and more. (p. 172, emphasis in original)

We can also find Resnick’s commitment to the power of socialization reflected in this description of Accountable Talk in an earlier essay on school reform, where she argued schools need to reject the belief that “native ability is the primary determinant in learning” and embrace the belief that “people can become smart by working hard at the right kinds of learning tasks” (Resnick, 1995, p. 55).

Accountable Talk refers to a particular set of discourse rules or norms teachers use to structure and control whole-class discussions. A discourse rule or norm refers to a conversational expectation. For example, when we pass someone in the hall at work and we say “Good morning,” we usually expect a response such as “Good morning” or “Hi, Michele, how are you?” or “Good morning, Sue, how was your weekend?” We don’t expect the response to be, “I like pepperoni” or “My cat needs to lose weight.” Those would be unconventional responses, or “not normal,” given the context. According to Resnick et al. (2010), the expectations of this type of discourse for the classroom can be categorized in three broad dimensions including: (1) accountability to the community, demonstrated by listening to and building contributions in response to those of others; (2) accountability to standards of reasoning, as demonstrated by using accepted standards of reasoning, meaning that talk emphasizes logical connections and presents reasonable conclusions; and
(3) accountability to knowledge, demonstrated by using talk based explicitly on facts, written texts, or other public information.

To anyone who has sat with 25 second graders and tried to have a conversation about anything they are learning or want to know more about Accountable Talk offers a structure for managing that event so the teacher can gain access to the “thinking, knowledge, and reasoning capabilities of their diverse students” (Michaels, O’Connor, & Resnick, 2008, p. 288). When these expectations are met, a discussion among a class of 25–35 students should remain focused on a specific problem for a sustained period of time. Students who do not meet these expectations can be deferred, redirected, or otherwise instructed on how to participate correctly. Readers are reassured that “Students who learn school subject matter in classrooms guided by Accountable Talk standards are socialized into communities of practice in which respectful and grounded discussion, rather than noisy assertion or uncritical acceptance of the voice of authority, is the norm” (Resnick et al., 2010, p. 180).

Accountability to the community refers to the norms for listening and building on the response of others. Students are expected to be able to rephrase what others have said or what an author has written (e.g., “Who can put into their own words what Serena just said?”) to demonstrate they have been listening to and understanding what the other person is saying. These norms support a more coherent flow in the conversation and reduce the number of seemingly off-topic comments, which in turn supports the likelihood students will meet the next set of norms and create logical connections and present reasonable conclusions. Meeting this latter set of norms requires an active role by the teacher, who guides the discussion by reorienting student attention to particular comments or questions, rephrasing utterances to emphasize their importance to the topic at hand, and creating the logical thread around which the reasoning crystallizes. This logical reasoning norm is further reinforced by the last category of norms—the expectation students will support or challenge claims and positions with evidence. The emphasis in this category is on ensuring teachers guide students (when necessary) “toward academically correct concepts” so they gain “fundamental knowledge,” which they in turn need to use in academic language and reasoning skills. Although the authors have categorized the dimensions of the talk for research and explanatory purposes, they explain the categories are irreducible in practice. For example, students can demonstrate they are listening, but in the absence of accountability to knowledge or reasoning they just cycle opinions, and all opinions are treated the same, uncritically. On the other hand, students could demonstrate accountability to reasoning with evidence, but if all their facts are wrong the argument simply spreads misconceptions and false information and is worse than no discussion at all. The authors explain there must be accountability to community, knowledge, and reasoning by all students all the time, and they understand this idealized version is no easy task.

Limitations and challenges of accountable talk. Michaels et al. (2008) acknowledge the biggest obstacles to using Accountable Talk (or similar types of deliberative talk)
are the social relationships in play between teacher and student, between student and student, and between teacher and student’s parents. Peers (and even teachers) may not respect each other’s points of view, may ignore them, or work hard to defeat them, based on their source rather than their merit. Students may resist the socialization of Accountable Talk because it contradicts the expectations they face in other contexts (in and out of school) or because there is a coercive aspect to the discourse. Students who have prior experience and feel comfortable with the norms can use them to control and devalue students for whom the norms are unfamiliar, intimidating, or distasteful. Not only do teachers have to monitor the talk moves and content of the talk, they also have to address negative social interactions and teach positive interactions. In our experience, how to achieve the necessary solidarity and positive emotional energy needed to ensure Accountable Talk norms are embraced and become desired by students is not typically discussed or considered part of Accountable Talk in teacher education or professional development. Like the KWL and the KLEW pedagogical strategies, the success of achieving Accountable Talk relies on the authority of the teacher who controls the entire process until the norms are finally adopted and used consistently and correctly by students.

**Structured assessment probes.** Just like the other strategies reviewed so far, the main purpose of the structured assessment probe is to uncover students’ prior knowledge on a new topic, identify preconceptions and misconceptions, and prepare students for conceptual change. The common format of a structured probe is a short narrative of a natural phenomena followed by a multiple-choice question reflecting the target learning goal and a call for reflection and explanation. For example,

Lance had a thin, solid piece of material. He placed the material in water and it floated. Lance took the material out of the water and punched holes all the way through it. What do you think Lance will observe when he puts the material with holes back in the water? Explain your thinking. Describe the “rule” or reasoning you used to you’re your prediction. (Keeley, Eberle & Tugel, 2017, p. 41)

According to Page Keeley and Francis Eberle (2008), “An assessment probe is a type of diagnostic assessment that provides information to the teacher about student thinking related to a concept in science. A diagnostic probe becomes formative when the information goes beyond merely knowing what students think, to using the information about student thinking to guide instruction” (p. 206). Unlike the KWL, KLEW, and Accountable Talk strategies, however, these probes are not intended to promote discussion among students, build their reasoning capacity, or socialize them to any particular type of discourse norm. Their sole purpose is to measure student understanding and/or to help teachers plan instruction based on the student responses. Designing structured probes is a complex process because they require field-testing to ensure validity and reliability, so schools and educators typically purchase them or attend training programs to learn how to create them.
Limitations of structured assessment probes. In her experience, Michele has found it is difficult to find structured probes that align to what she finds important to measure. They present a narrow range of what is considered important to know. Also, because structured probes often ask students to choose a correct answer or scenario amid a set of alternatives that sound reasonable, she wonders whether the structured probe helps students develop misconceptions they would not have formed otherwise. Furthermore, once she has the student data, it is not clear how the results inform her instruction. Before she administered the probe, she already knew students knew little about the topic; after administering it she is still not sure she has uncovered all these ways the students are thinking about the topic, only the ways the probe allows her to measure.

The KKS-IP

The KKS-IP described in the beginning of this chapter is similar to the KLEW, KWL (as intended by Ogle), and Accountable Talk methods because it asks students to reflect on what they know and how they came to know it, listen to others, and engage in dialogue. However, the similarities end there. It was not designed to replace any of these strategies, nor were these strategies reviewed in the design process. It is only as teachers like Michele have started to use this tool in instruction that they themselves have drawn these comparisons. The KKS-IP was initially designed as a way to teach young children the nature of scientific evidence and to demonstrate to students (through their own research activity) the pervasive use of evidence as a discourse tool in knowledge-acts performed by the students themselves, their peers, their teachers, their parents, their friends—everyone. Only by raising up their everyday practice of inquiry, however, did we feel we could interest students in comparing how they and their community members performed knowledge-acts with how people called scientists performed them. We argued that the process of being/becoming a scientist means one must be able to raise up any everyday practice of using and creating tools for thinking for scrutiny, reflection, critique, modification, and transformation.

In our experience to date, one of the major benefits (identified with Michele within her practice) of immediately positioning students as researchers who are responsible for gathering and analyzing data is that the practice and products generated can be used to assess a wide variety of student and teacher actions, including:

- Radical listening and joint problem solving
- Reasoning with evidence
- Commitment to credibility
- Developing research capacity
- Learning multiple perspectives and developing mindfulness
- Providing structure(s) for practice
- Describing and confronting values and habits through self-reflection
• Documenting independent and persistent use
• Being/becoming scientists
• Evaluating instructional planning and teacher role

We will review what we mean by each of these claims, but first we would like to acknowledge it is even more important to transform these apparent benefits into the teaching and learning object–motive or problem-space than it is to adopt the KKS-IP in the absence of these. It is not the protocol that guarantees these outcomes; it is the use of this protocol in conjunction with an understanding on the teacher’s part that the point is to use it to engage students in research on how people (they and others) come to re/produce tools for thinking and how people use these tools to accomplish knowledge-acts. Without this teaching object–motive, the KKS-IP runs the risk of becoming another pedagogical tool used mindlessly, as its history and original purpose are lost and it is transformed into a static procedure students follow without knowing why or how it is meant to benefit them. Adopting a pedagogical approach such as this KKS-IP, the KWL or KLEW procedures or Accountable Talk should always be done with the understanding that adoption is driven by agreement or curiosity about the purpose and intention of the approach itself (e.g., promote teacher listening, promote equitable participation, promote science process skills, promote inquiry). Modifications to the tools (the charts, interviews, prompts) can and will need to be made during the integration process, but they should be made in light of a larger purpose or object–motive of teaching and learning, and the change should be tested for effectiveness.

Radical listening and joint problem solving. We have had students report to us that when they are in the role of an interviewer they feel responsible to hear, document, and question every word their RA says. We believe when teachers decide to use assessment strategies like KWL and KLEW or Accountable Talk (or, in our case, the KKS-IP) they are probably interested in promoting this kind of radical listening described by the students, but they rarely achieve it. According to Ken Tobin (2012) citing Joe Kincheloe,

Radical listening requires each participant to understand the standpoint of others, figure out how to adopt those standpoints, consider implications of adopting them, and in ways that are reminiscent of thought experiment, consider implications of adopting practices that are consistent with others’ standpoints. Rather than immediately searching for the shortcomings of a particular standpoint, radical listening necessitates the identification of its inherent strengths. The listener is required to understand and apply someone else’s standpoint and carefully consider plausible outcomes and their viability for this collective—in this case a science class. (p. 11)

When students interview an RA we can take it as an opportunity to assess the progress they are making on radical listening. For instance, if an RA’s answers are
unclear, or if he or she did not understand the question, then the interviewer might ask the respondent clarifying or additional questions to learn more and help the RA share their perspective. Questions we encouraged students to ask included:

- What do you mean by that?
- Can you tell me more?
- When you say _____, do you mean ____ (offering an alternative)?
- Could you tell me your reasons for making that decision?

When interviewers decide and assess for themselves what questions they think will help them learn more from the RA and their perspective, we believe this demonstrates the interviewer is truly thinking about what the RA is saying, analyzing the response, finding its strengths, and expanding his/her own ideas about what is considered knowledge and knowing. By engaging in a radical listening process the interviewer and RA have the potential to learn new ways of exploring and interpreting the world that might not have occurred to either of them alone or prior to the interview.

When students took the interview protocol home and recruited research associates after school for the first time, we found they often approached us and told us about the experience (e.g., “My dad didn’t like being interviewed” or “My mom couldn’t think of answers so I had to tell her how to do it”). These unsolicited reports led us to ask students to describe the interview experience and reflect on what it felt like to conduct the interviews. Their responses indicated they were engaged in radical listening because not only did they hear and record the RAs’ responses, they also heard the ease, agreement, confusion, or struggle the RAs experienced as they were asked to reflect upon and discuss how they came to know what they know. We believe this in itself can move interviewers to develop and ask additional clarifying questions, or to revise the questions to be more suitable or clear to the RA answering the questions. We believe the unusual degree of engaged listening we witnessed emerged spontaneously from positioning the student as a true researcher. The nuances seemed to matter much more to students than simply finding (and checking off) a factual answer.

Teachers can also monitor whether and how students engage in joint problem solving. For example, depending on the claims RAs made, occasionally they would get stuck and have trouble answering one of the four questions. Given the nature of this authentic research project, copying or mimicking their neighbor’s answers is not an option for a peer RA, and it challenges the interviewer to devise additional encouraging questions that will coach the respondent in answering. On the one hand, if a peer RA continues to have trouble, then this helps both the interviewers and RAs realize more work, research, and investigating needs to be done in order to support a claim of knowing a particular scientific idea about a topic. On the other hand, if a peer RA makes connections between the questions and establishes the significance of the work she’s done to grow her tools for thinking, it becomes evident to all stakeholders that the RA’s claim is likely to be credible and can probably be supported by even more evidence and through further research.
Teachers can monitor the quality of the radical listening by paying attention to the ways interviewers problem-solve with peer RAs including the types of follow-up questions they generate and the extent of the connections they are able to make to their own perspective.

**Reasoning with evidence.** We can call for reasoning with evidence as loudly and as frequently as we want, but until students feel compelled to provide evidence for a reason, they are not going to produce what we consider relevant and high-quality evidence. By using the KKS-IP as part of a teaching unit, however, teachers can challenge interviewers to insist on convincing evidence from their peer RAs. With this as the object–motive, students can call for reasoning with evidence independently; they don’t have to be prompted (or hounded) further by the teacher. We recognize this reconstruction also opens doors for students to investigate what we mean by convincing evidence, but before studying that type of evidence, teachers can use this reconstruction to assess both interviewers and RAs on their evidence production actions. As interviewers ask the series of questions in the protocol, it becomes very evident to the interviewer when an RA does not truly know or understand the claim he initially made about the topic being researched. When this happens, the interviewer’s follow-up questions typically take the form of calls for evidence, and teachers can monitor how the interviewer formulates these calls and how the RA answers.

In our work with students using the interviews in and out of class, RAs of all ages report that they find answering the interview questions challenging and thought provoking. Students have told us that when they are asked how they came to know something and they initially say they “just know it,” the interviewer quickly reminds them the nature of the interview does not support that as an answer. Many RAs report (or are observed) struggling with explaining why they think their sources are trustworthy.

Both RAs and interviewers appear to become more conscious of how they and others know what they know and decide what sources to trust. Teachers can monitor this consciousness by noting how students answer these questions and how interviewers develop follow-up questions to help them.

**Commitment to credibility.** Some sociologists of science have concluded career scientists are often concerned with credibility before credit. In other words, they prefer to be “right” or reliable more than they prefer to be famous. It is not surprising scientists like to seek out and be credible sources of tools for thinking. Think of how upset we are when someone deliberately misleads or deceives us, or how annoyed we are when we find out something we took for true or reliable turns out to be “wrong” or unreliable, particularly if have been sharing this with others or using it to make decisions. Teachers can raise the issue of credibility (what it is and why we value it), but it must be the students who feel the need to call for it.
We created this desire and need by asking students to consider whether they agree, disagree, or remain undecided about the claim–evidence conjectures made by RAs. We explained that when we agree with an RA’s claim–evidence conjecture it means we adopt it as our own, we are willing to defend it, and we trust it will be useful for various knowledge-acts. Disagreeing with an RA’s claim–evidence conjecture, on the other hand, means we reject it, do not find it useful as stated, and we may or may not have evidence to challenge its trustworthiness or utility. Finally, when we are undecided it means we have unanswered questions that need to be resolved.

When students engaged in this exercise, their decisions appeared to be based on the perceived credibility of the claims. They worked together to crosscheck the evidence given (e.g., How did you come to know this? Why do you think it is true?), and they eventually explained why they agreed or disagreed with the claim. As students considered the credibility of various claim–evidence conjectures and accepted or rejected them, they explained their reasoning. This reasoning reflected their assessment of their own position. In the process, students can change their minds if they see value in any of the arguments about the claims or the qualities of the evidence provided among peers. Teachers can use this discussion to monitor how and why students change their minds (or not) as well as the questions they generate in this process.

*Developing research capacity.* Science educators value science process skills, including observing, inferring, measuring, communicating, classifying, predicting, controlling variables, defining operationally, formulating hypotheses, interpreting data, experimenting, and formulating models (Padilla, 1990). As students engaged in research activity shaped by using the KKS-IP at the beginning of the unit, it became possible to justify they were learning how to do many of these skills. First, we found it inspires curiosity (among students and teachers) as well as a desire to develop ways to find out more about the concept as part of classroom work. Second, students collect data, which they then can use as evidence when they are asked to support or challenge a particular claim. Third, instead of assuming they have learned something, they analyze the data they collected to be sure they have tangible evidence and can assess their learning and understanding for any claim they make about their new science concept knowledge. Fourth, the last question of the interview, “If you could prove it, what would you do?” affords students the opportunity to choose and develop a fair test, practice science process and critical thinking skills, refer and respond to literature as researchers, move through logical procedures, and continuously reconsider and assess their own learning. Finally, students revisit, revise, argue, enhance, and support their knowledge through repeated uses of the KKS-IP. In response to this skill development, teachers can further develop and individualize lessons and a rigorous curriculum that supports engagement, learning, reflection, and a classroom environment that inspires inquiry.
We are not surprised students can do such a wide range of process skills as they conduct their research, but do they appreciate why these skills are valued in science, and will they choose to do them on their own? We are not sure we’ve addressed this in our own work yet, but we believe studying knowledge (tool re/production and knowledge-acts) and exploring why some methods work better than others for determining claim trustworthiness and credibility is an obvious way to provide space for students to create their own value statements about various process skills. Plus, it’s the type of investigation that seems to hold their interest.

Learning multiple perspectives and developing mindfulness. Late in the process of writing this book we came across the work of Ellen Langer, a psychology professor and researcher who has developed a conception of mindfulness after many years of research on mindlessness. In her book, *The Power of Mindful Learning* (1997), Langer explains mindful learners “implicitly or explicitly (1) view a situation from several perspectives, (2) see information presented in the situation as novel, (3) attend to the context in which we are perceiving the information, and eventually (4) create new categories through which this information may be understood” (Langer, 1997, p. 111). After reading this definition, we realized teachers might be able to use the KKS-IP interaction as a way to assess mindfulness or ask students about this list of mindful qualities. For instance, as interviewers witness an RA’s thinking and answering process, what type of answers are they anticipating? What do their expectations say about their own perspective? What kinds of connections are they making between their own ideas and the respondent’s answers? Are they able to compare their experiences? Do students come to realize each person’s experiences (though the same in some instances) are colored with that individual’s perceptions and backed by each person’s tools for thinking and prior knowledge-acts? This is an area we are beginning to explore further.

Promoting positive student engagement. Students report they enjoy the interview process and it is an uncommon school experience in their lives. Furthermore, students report they are waiting to talk during “turn-and-talk” exercises, but when they are interviewing they are listening carefully to the RA and devising ways to learn more about what their RA said. To our delight the environment created when we engage in this research is multifaceted enough to engage the students who otherwise display a lack of willingness to participate in discourse.

We are endlessly pleased to find students enjoy conducting the interviews (as well as being interviewed) and are excited about listening to others. We wonder whether the KKS-IP has replaced the consumer aspect of acquiring information prevalent in education with becoming empowered to listen critically, be skeptical, and develop ways to create evidence. Students are truly accountable, responsible, liable, and occupied in comprehending what others are saying. They make their own choices in deciding what to share, knowing they are going to need to justify what they are saying. As a result, students are engaged and ready to take action.
We can use the KKS-IP to assess student engagement by monitoring the extent to which students who are typically very quiet change their participation in classwork after the introduction of the research project and KKS-IP.

Providing structures for practice. We often hear educators refer to doing science, but the phrase talking science is considered more meaningful (e.g., Lemke 1990; Roth 2005). Students don’t typically struggle with the physical aspect of doing science (e.g., mixing solutions, building ramps, spinning tops, flying model airplanes); they struggle with the talking and process aspects of doing science (e.g., making observations of animals, describing chemical reactions, inferring from observations, explaining why the airplane flies, creating models to demonstrate how the spinning top works). Providing students with space and time to practice talking scientifically is as important as providing them with time to practice doing scientific investigations and manipulate materials. Using the KKS-IP allows us to assess how well students are talking science. What we find when we observe students during interviews is students are challenged by the tasks embedded in the questions. We believe this is because, although they are expected to be skillful at these tasks, there are only rare instances where they are taught to do and practice these tasks in a purposeful, context-based and effective way. We can use the interview process as an opportunity to transform the science classroom into a workshop of tool and knowledge-act re/production and reflection where students purposefully practice skills and discover why the interview process is potentially important and useful in all aspects of their lives.

Describing and confronting values and habits through self-reflection. Earlier we explained that one difficulty with studying tools for thinking in our everyday knowledge-acts is their ubiquity and familiarity. Because students produce claims and evidence in their daily lives and they witness others doing it all the time, it is important to find ways to highlight these tools and their re/production processes. As students begin learning how to identify claim–evidence conjectures they inevitably reflect on their learning process, what sources they value, and how they judge the credibility of sources. We can use this activity to assess the extent of self-reflection and study how students describe and confront their values and habits.

Documenting independent and persistent use. When we first introduce and teach a fundamental tool for thinking (in this case, how to research knowledge production), we like to monitor whether students find the tool compelling and useful in their daily lives. The ease with which many students incorporated the questions from the KKS-IP into their discourse habits suggested to us that these might have been questions they themselves have always had, but have never had the words or encouragement to explore. Students have told us they will practice violin differently, or pay attention more to the placement of their arms while ice-skating. They tell us their instructor told them they had to do these actions, but
never told them why. Based on their research projects, they now feel they know why and, if not, how to find out.

**Being/becoming scientists.** As we discussed in Chapter 2, there is no gap between changing one’s world, knowing one’s world, and being/becoming oneself. These are three aspects of a holistic approach to human development. These aspects form a continuum and do not occur independently, but rather reinforce each other (Figure 2.2). When students study what and how they know their world, we can turn their attention to how this same knowledge can change the world and how they view it, as well as who they are and who they want to be as part of it. We’ve already seen it help even the most introverted student act boldly during the process of learning more about something. The research focuses students on the phenomena of their own ways of being as learners and knowers in the world outside the classroom. Not only are students reflecting on the learning process, but they are also developing a collaborative environment for critical scientific discourse that includes argument, reasoning, decision-making, and the production of tools for thinking.

**Evaluating instructional planning and teacher roles.** Using the KKS-IP and positioning students as researchers generates new roles, responsibilities, and opportunities for teachers. We can use our assessments of student performance to inform and assess our own practices including our (1) overall science lesson planning including what topics to cover and how to engage students as researchers of tool production as knowledge-acts with new tools; (2) familiarity with students interests and their access to science-related resources outside of school; (3) decisions about when to use explicit instruction and modeling; (4) ability to connect learning object–motives with what students value, choose, and desire; (5) assumptions about what children can and cannot do; and (6) ability to inspire students to take these research questions beyond the classroom and integrate them into their everyday actions.

We find we enjoy studying and learning about how we believe we produce various tools for thinking and perform knowledge-acts and learn more about what the people around us believe. Rather than focusing on right answers, we focus on learning about what interests us and what matters to us, how we find out more, how we evaluate what others tell us, and, most important, where ideas come from, who generated them, and what problems they might help us solve.

**CONCLUSION**

The KKS is intended to help students and teachers engage in research on how we, including others in our communities, come to know what we know. The various research protocols (IP, DP and CSP) are simple and easy to use and modify as necessary for related research studies. Working on a KKS is empowering because it takes the mystery out of learning by studying the re/production and use of tools for thinking. How do we support the development of curious and creative
student-researchers without monitoring and supporting 25–35 independent research projects (or >250 in the case of a science cluster teacher)? In this chapter, we have presented one solution that worked for us. By establishing an ongoing, large-scale, multi-year study with students, and teaching them how to use a variety of research protocols, we have easily managed both student-led and teacher-led sub-investigations over the course of a school year. A KKS like the one researched as part of the Scientific Thinker Project and presented here has many of the same goals as currently popular approaches including KWL, KLEW, and Accountable Talk, but resolves the lack of student-led inquiry missing in these approaches. By employing versatile and intuitive research protocols that reflect a learner–scientist perspective, we made it possible for students and teachers to engage in research with minimal preparation. By studying what people mean when they say they know something, student–researchers are immediately positioned to learn that everyone accesses similar sources, but people vary in the resources they prefer and how they determine what is trustworthy and what is not.

Based on our experience we now view the KKS as an essential foundation for science teaching and learning. Not only do student-researchers engage in many scientific research practices (observing, documenting, measuring, inferring, communicating, classifying, defining operationally, interpreting data, and formulating conclusions), they also are simultaneously studying how they and others (peers, community members, family, career scientists) perform these actions. We have not yet conducted longitudinal studies, but our short-term (and occasionally anecdotal) evidence indicates that participating in a KKS clarifies for students the purpose and utility of a tool like evidence, which is so prominent in all scientific discourse practices, including observation, argumentation, and explanation.
OUR STORIES

Our Stories of Being|Becoming Educators and
Learner–Scientists and of How We Met

In this section we provide abbreviated, scholarly autobiographies because we recognize they provide a context for the research and practice reported in the previous chapters. As we explained in the Introduction, we began working together in 2003 and have co-taught or worked in parallel at different schools in New York City since then. Here we share a few snapshots of our interests and work prior to our meeting and a bit more detail of what happened after.

Michele: I hadn’t planned on choosing elementary education as a career. But when I took the opportunity to volunteer in the local environmental education center, I enjoyed it so much that my decision to become a teacher was made. I was a hairdresser at the time and already enrolled in evening college classes, so I completed the requirements for an education degree. The coursework in education helped me to reflect on my early childhood school years and how my teachers and parents supported my growth as a curious person who wanted to know more about the world. I was very motivated to support a new generation of students.

I have been fortunate to spend my entire teaching career thus far working in schools that are within three miles of the Flushing, Queens community in which I grew up and was educated. I am still in touch with a few of my elementary school teachers, and nothing makes me happier than seeing some of my former students from two decades ago. Working with Sue afforded me the opportunity to teach teacher education classes alongside some of my dedicated education professors at my alma mater, Queens College. For eight years there I’ve taught various undergraduate and graduate science and math methods classes that involve students with community resources relevant for teaching those subjects. The school I currently work in is on the college campus. My experiences make New York City seem like a small town.

I spent my first nine years teaching kindergarten and first grade in a public, city school. The school lacked important instructional resources and there was no prescribed science curriculum but I saw how the students looked forward to the creative science teacher who inspired them once a week with her rolling-cart of portable nature. Almost all of my students spoke languages other than English. Most of them could not communicate with each other, as they did not have a language in common. I was not prepared for this as a teacher, but I was prepared for this as a fellow human. Observing these children interacting with each other and the world around them led me to question how much I knew about teaching and learning. Everyday school routines helped me to find out that the majority of these young
children were helping their parents assimilate in the community. As they learned to speak English, they were translators for their parents at the bank, supermarket, and during parent–teacher conferences. They were 5 years old. I became sure that there was nothing that they could not do, and I led class with that understanding. Still, I wondered how they came to know all they knew. I realized that becoming a teacher forever changed me as a person because of the children I was lucky enough to spend my days with. I knew I needed to learn more about knowledge production so that I can improve my teaching practice and meet the needs of diverse student populations.

I transferred from there to teach at a different New York City public school only because of the greater opportunity to be a teacher-researcher and improve my practice. It is the school where I currently work as an early childhood science cluster teacher. In this role I serve the kindergarten thru third grade population of students. Each class travels to my classroom/laboratory three periods a week. I spend one extra period with the third graders, which allows the students to develop longer-lasting investigations. I gather once a week with their teachers to examine and compare student work. We analyze our practice and uncover prominent student trends so that we can enhance our teaching, build a common language, and better attend to student needs. I collaborate with the upper elementary and middle school science teachers with whom I plan long-term goals. Twice weekly, I support a rotating group of students as we cultivate our school garden. We compost to nurture our vegetables, herbs, and flowers that we grow indoors and outdoors in four raised beds that students and their parents built. The excitement and learning that stems from our garden is boundless.

When I was first hired as a second grade teacher, however, the science curriculum was predetermined. I was to teach science using kits from the Full Option Science System (FOSS) purchased for the school from Delta Education. I wasn’t sure what the students should do and learn from the contents of the boxes. I haven’t had experience teaching from a kit. I wondered why students needed to know this and not other things. Why had these kits been chosen as the science curriculum? What about the experiences the children are coming to class with? Will these kits provide me with the tools I need to meet the different needs of students? I knew I needed a better understanding of how students learn science and how best to teach. That’s when I met Sue.

*Sue:* When I came to New York in 2003 to teach in the elementary education department at Queens College-CUNY I began reading some of the works by activist scholars (e.g., Freire, hooks, Kincheloe, Meyer) and working with Ken Tobin’s group at the CUNY Graduate Center. In my teaching I was struggling, not with the content, but with resistance from students. Many students, teacher candidates in a childhood and early childhood education masters program, openly challenged my teaching ideas and my experience as a scientist and teacher. This sub-group
dismissed my model lessons and informed me, “Kids can’t do this!” and they argued that I had no proof children were capable of doing the lessons I was teaching them to develop because, they said, “You’ve never been an elementary school teacher.” Technically, they were right. I was a scientist, which to them meant I could not also be a science teacher.

As an undergraduate I majored in biochemistry at Mount Holyoke College where I worked on three projects over four years. At the National Institutes of Health I studied the molecular mechanism of DNA repair with Eric Ackerman; at the Woods Hole Oceanographic Institution I attempted to clone a green fluorescent protein from a type of comb jelly with Douglas Prasher; and at MHC I helped determine the evolutionary relationships between a contested group of ferns with Diana Stein. I went straight from my undergraduate college to Harvard University to earn a doctorate in cell and development biology and then to the University of California at San Francisco for a post-doctoral fellowship. As a doctoral student I researched how the immune system develops in Marjorie Oettinger’s lab and as a post-doctoral scholar I studied how the nervous system develops in Cornelia Bargmann’s lab. I made original contributions to all of those fields in the form of publications, but the QC candidates were more concerned that I had never been a classroom teacher. I had worked as a college professor (adjunct) for two years and as a volunteer with the UCSF-Science and Health Education Partnership for three years. I had experience teaching science to and with elementary, middle, and high school teachers and their students in the San Francisco Unified School District. As a result, I was confident my models of teaching and learning were not only realistic, but also reasonable. I believed if learners were interested then teachers could make science relevant and accessible. The QC candidates were not in agreement because I had never been a classroom teacher. I began to believe I was wasting my time in science education even if a minority of candidates I taught would never attempt to teach science in the ways I was advocating until I had done more of it myself. That’s when I met Michele and had the opportunity to work daily with students and teachers in a public school during the school day for a sustained period of time.

Michele and I have been working together on and off for the last 10 years. In that time I have not only co-taught children (and teachers candidates) for hundreds of hours, I have reviewed and analyzed even more hours of classroom interactions during science teaching and learning activities (including interviews, small-group, and whole-group conversations). Through multiple perspectives as a biologist, teacher, educational researcher, and teacher educator I continue to study the production of educational experiences and environments for teachers and students.

Since coming to New York University in 2007, I have focused on challenges science teachers face, particularly with planning and implementing elementary science curriculum and instruction. I am currently developing and studying instructional resources that use the Being and Becoming Scientists Today framework and embody the collaborative transformative practices presented in this book.
How We Met

We met in 2003 at a professional development session. Michele was teaching at a school where Sue conducted a professional development session on science teaching. In that presentation Sue mentioned she was interested in getting more classroom teaching experience and conducting research on how children learn science. During a break, Michele mentioned she was new to the school and was looking for advice about how to teach science out of a box. After a brief chat, we exchanged schedules, and soon were co-teaching science almost daily in Michele’s second-grade classroom.

The school had adopted FOSS as the school’s K–5 science curriculum and all the teachers in these grades were given three units specific for their grade level. Michele and the other 2nd grade teacher at the time had been given the FOSS kits: Balance and Motion (physics), Pebbles, Sand and Silt (geology/earth science), and Insects and Plants (life science) and were expected to use them for science instruction. When we started working together, Michele was finishing up the physics unit and preparing to start the earth science unit. She gave Sue the teacher manual and a list of questions she had generated after reading it.

After conducting an inquiry process very similar to the energy inquiry described in Chapter 4, we concluded that the investigations in the unit were not only decontextualized but they weren’t likely to advance students’ capacity for talking and thinking scientifically or for observing the world geologically. We developed an alternative instructional sequence using the materials provided in the kit and we supported as many student-led investigations as possible. We ended up covering more content (more thoroughly) than prescribed in the kit and students were even pursuing independent investigations at home. Soon parents were insisting both second grade classes receive the same experimental curriculum! The principal at the time agreed we should expand our work the following year to include the entire second grade. Once we gained permission to conduct research at the school and secured consent from students and families, we were able to begin incorporating video research into our coplanning and reflection routines.

Looking back on some of our early reports to granting agencies we have consistently been interested in studying ways to create learning environments where students could learn to respectfully ask (and answer) the questions, “How do you know?” “How do you know it wasn’t because of ______?” and “What if ______?” in appropriate situations. This earlier research interest developed over time and eventually crystallized into the Knowledge and Knowing Study presented here and now being used as a model for developing similar instructional resources and learning tasks.
A Q&A SESSION WITH THE AUTHORS

A Brief Dialog in Response to Two Questions that Arose after We Finished Writing and Began Sharing Parts of This Book with Colleagues

1. Teachers and principals today face unprecedented demands to meet new state and federal accountability standards. What do you say about the BBST framework and the KKS tools to those who feel like they are doing all they can to just survive in the classroom?

Michele: I was one of those teachers who felt like I was doing all I could do to just survive in the classroom. With learning about and complying to the new accountability standards came less time to re-construct a curriculum that made sense and was designed to meet the needs of the diverse student population I face everyday. These are some of the ways I think the BBST framework and the KKS tools have alleviated some of the pressures I face in the classroom:

• The learner–scientist perspective embodied in the BBST framework is specifically guided by a deep consideration of the nature of scientific knowledge. Student understanding of this crosscutting theme has long been a goal of local, state, and national science standards, therefore, this framework allows us to facilitate teaching and learning in that area.

• The questions within the BBST framework help teachers develop curricula from a learner–scientist perspective.

• The questions within the framework can also be used as an empowerment tool to encourage students to use their own questions to learn about their world outside of school and in other school subjects.

• The instructional planning tool provided in Appendix F not only organizes learning actions, but I have found it can also serve as a helpful reference to fulfilling the standards, including families and school community in the teaching and learning activities, and making connections to all curriculum areas.

• The protocols or tools used in the KKS can be adopted and used to launch each instructional unit and engage students and families immediately at the start of a new topic.

• The artifacts generated from using KKS interview and decision protocols allow teachers to quickly assess students’ knowledge base, the progress of their communication and reflective practices, students’ overall interest in the work, and the quality of the learning environment. They provide an efficient way for
teachers and administrators to gather evidence of growing teacher practice and student learning.

- Students can use the KKS protocols, and artifacts from using them, to learn not only what their peers know and understand, but also how and why science knowledge is produced everyday by people they know.

For these reasons, the BBST framework helps me to overcome the challenge of time constraints while meeting new demands in an organized way. I am no longer trying to survive; I am purposefully active and I look forward to learning and teaching alongside the students.

Sue: Michele’s work, critical reflection, and feedback have made it possible to begin to unpack the potential strengths and benefits of using the BBST framework and the various tools for thinking described in the book, which all need to be investigated further. We have aimed to create a variety of resources that are fun and relatively easy to use, but also produce meaningful artifacts teachers and administrators can use for a variety of assessment purposes. I wholeheartedly agree with Michele’s list and would only add that much of it stems from rethinking the three-legged stool model and creating a view of science from a learner perspective. When educators embrace the notion of a learner perspective they are well on their way to helping students develop the tools for thinking that they need to learn anything.

Michele: It’s been great to see how students have independently devised ways to use the various tools as springboards for their own continuing research. I saw how adopting a learner–scientist perspective led to students expressing empowerment in their work, but I want to explain how the BBST framework has made me feel more confident and empowered as a teacher. I embarked on this journey with Sue ten years into my teaching career and this work has transformed what I already loved to do. I was beginning to feel overwhelmed and discouraged. I had enough experience to know young students were capable and excited to learn and explore their wonderings, but I recently was overwhelmed from having to learn new accountability standards. That work left me at a loss for finding the time and meaningful ways to engage the curious students in my classroom everyday. I felt so strongly that there were gaps in prescribed science curriculum resources and that students’ excitement for learning was falling through those gaps—being lost. These resources described in the book have closed those gaps and are leading me to capture and use students’ questions and discourse to help enhance their responsibility for and interest in learning. I am so excited about how much has emerged from this. Now, when I analyze my students’ work, the next individualized instructional steps that we need to take are easily apparent.

Sue: For me, one of the hardest parts of working together was to see Michele starting to feel overwhelmed. Although she never succumbed to that feeling it was there. I knew, from all of our work together, Michele was committed to and successful at
helping students develop a variety of myth-busting tools for thinking in science. Her critical stance allowed her to see a prescribed science curriculum cannot be treated as a fixed formula. It has to be viewed as one of many resources in our teaching toolbox. If practicing teachers can use the protocols of the KKS, the lesson planning tools, the media analysis guides, and the guidelines of the BBST framework—along with processes like critical questioning and generated myth-busting tools for thinking—to revise their science curriculum, then I think they’ll start feeling as empowered as Michele (and the students) does.

2. How did you select the references you used in shaping the BBST framework and for addressing the questions learners ask?

Sue: My process wasn’t much different than the one we used in Chapter 4 with our study of energy – reading with specific question(s) in mind. The story of the BBST framework was spread over a much longer period of time, but is a similar process. When I first began thinking about being/becoming an educational researcher I was referred to some classic texts by Lev Vygotsky, John Dewey, Maria Montessori, Jean Piaget, Jerome Bruner, bell hooks, and Paulo Freire many of the same readings teacher candidates get in foundation or theory courses. At the time I was struck by their similarities. They all had classroom experience; they all had conducted research on teaching and learning; they all talked about the dangers of authority and coercion in the learning environment; they all talked about imagination and creativity; they all talked about interest, motivation, and a desire for purpose; they all placed the learner at the center of the any curriculum design; and they all presented compelling models of instructional design (at various stages of development) grounded in good working theories of learning and development. It took me a couple of years to understand there was much more to Vygotsky’s work than the catch phrase “learning is social.” One of his most important contributions, in my opinion, was his explanation of how learning can and does lead development—an explanation that clarifies the essential role of teachers.

Most scholars, researchers, and teachers working today, who are using the works of Vygotsky (and his colleagues Luria and Leontev) to pursue open questions about human development, typically employ some variation of what is called Cultural-Historical Activity Theory or Activity Theory. Once I learned that fact I was able to track down scholars and teachers who were designing and testing lesson plans and curricula using principles derived from Activity Theory. In other words, from this working theory of how people learn originally developed by Vygotsky and continually being revised and expanded upon by others, educational researchers and teachers were making and testing assumptions about how to design instruction and instructional resources to ensure learning and learner success on various measures. I discovered Jerome Bruner’s middle school sociology curriculum (Man—A Course of Study), Galina Zuckerman’s work in elementary school science, Harmut Giest and Joachim Lompsher’s lessons in math and physics, Lada Aidarova’s early childhood
literacy curriculum, Vasily Davydov’s elementary math lessons and curriculum, Jean Scmittau’s curricular analyses, and Mariane Hedegaard and Seth Chaitlin’s middle school units on history and biology, among others. These resources were crucial to my personal development as a curriculum designer, teacher educator, and learner.

It was during my quest to learn more about the relationship between learning, teaching, and development in order to establish more general principles for instructional design in science to test and eventually share with teachers that I met Anna Stetsenko. Working with Anna and reflecting on her work developing the concepts of contribution and transformation within the context of working with Michele and other classroom teachers helped me crystallize the BBST framework in its current form.

So, it wasn’t a matter of selecting the references as much as it was reading with a question in mind, following where the readings led me, and being fortunate enough to meet people in the field who were generous with their time and willing to teach. However, it wasn’t until I saw how the framework graphic resonated with Michele as an early childhood educator and teacher educator that I felt comfortable pursuing it further.

Michele: As a teacher candidate, I read most of the classic texts Sue mentioned and I was not sure how or when I would apply what I’d read. At that time I was very interested in literacy and language acquisition. What I learned from those texts helped me as an educator to make useful connections in my planning and teaching practice between Vygotsky’s theory of learning and Rosenblatt’s transaction theory of reader-response which highlights the role of the reader in creating and developing meaning. As we began to work together and Sue introduced me to various other relevant theories including CHAT, I recognized more clearly how young students need to develop their role in creating meaning for themselves not only in literacy; but also, in science. The framework she introduced me to was so inspiring at a time when I was starting to feel inadequate to teach science in spite of my experience. In addition, prior to our work together, I had a decade of educator experience driving me to believe students can be motivated to learn how to create success for themselves with the mediation of an effective teacher as they learn science. However, I did not have, in my toolkit, a guide to put together my understandings so that I could transform my teaching and enhance student learning. Now, I confidently return to the ideas embedded in those theories and resources with a new perspective and flexibility in practice as we plan instruction together.

Sue: Michele mentioned Rosenblatt’s transactional theory and I realize we did not draw on her work explicitly in this book. She was well connected to a number of influential thinkers of her time (e.g., John Dewey, Franz Boas, Margaret Mead, Maxine Greene, Catherine and Gregory Bateson) and that got me wondering about whether she had ever met Vygotsky or worked with one of his colleagues or
students. This, of course, led me to the Internet (as our young students are always telling us, “Google it!”). In an interview conducted by Philomena Marinaccio in 1999, Rosenblatt did mention the influence of Vygotsky’s ideas on some of her thinking, but what was more thought provoking was her answer to a question about her current interests at the time. Rosenblatt explained she was struggling with continuing a fuller discussion of her theory of writing, but she was torn between conducting scholarly writing and taking more immediate action to change the world. She explained this conflict existed primarily because she felt our democracy was threatened from within our own borders more than ever before in her lifetime (remember she witnessed both internal and external threats from antidemocratic, totalitarian forces in the 1930s through the 1950s). At the core of her current conflict was her original concern in the 1930s—that traditional teaching methods were producing shallow and unquestioning readers who passively accepted the authority of the printed word (Rosenblatt, 2005).

What has happened is that we teachers have not communicated with the public enough, with the parents and particularly with the public that does the voting, to make them understand what it is we are trying to do for their children. If they accept some of these quick answers, these speedy answers to educational problems that are being offered to us, they may seem to be helping their children but in the long run they are going to create a world in which their children are going to have to live, where there will be terrible differences in wealth, in education, in health and in every other way. I feel we really have to be devoting our time and efforts to criticizing these shortsighted political solutions, and demanding revisions. That’s why I’m conflicted. On the one hand, I have this urge to constantly try to explain what I am driving at in my own thinking about reading and writing. On the other hand, I feel that all of us ought to be concerned about this broader political, economic problem. (Marinaccio, 1999)

This quote from Rosenblatt carries an urgency we have tried to convey in our work and through the creation of the BBST framework. Just as one of Michele’s heroes, Rosenblatt, struggled with short-term realities and wanted long-term vision, we face the complexity of human lives—those of the children or teacher candidates we teach everyday. As a result, we often feel we need rapid solutions. But we don’t. What we need (and what we’ve tried to create in the BBST framework) is to construct partnerships in learning with our students. This doesn’t need to be complicated, however, and we could argue there are two major elements for success. First, by positioning young students as researchers of knowledge and knowing, we can equip students (and their teachers) with the ability not only to recognize misinformation as a type of myth-sustaining tool for thinking, but also to create the myth-busting tools necessary for the critique and change called for by Rosenblatt. Second, by adopting a learner perspective in all areas of education (not only in the sciences), we can
support children in learning about what they can do now and in the future to shape the way we meet our basic needs (food, clothing, shelter, and health care) and live full and joyful lives beyond science.

We have focused on science because of our interests, current positions, and the financial support we have received, but it’s important to note (as Michele has previously) that the BBST framework, the content inquiry guides, and the Knowledge and Knowing Study are adaptable to any subject area, age-level, or educational setting. I think this is a testament to its strong theoretical basis, which we continue to expand and develop.

Michele: Sue’s spontaneous and timely research of Rosenblatt’s reflections makes me even more excited and aware of the compelling connections our current work has with the theories that inspired my early teaching practices. Sue’s comment reminds me that it is important to keep in mind we face many of the same concerns these earlier educators faced and the cultural tools for thinking they produced are relevant to us today.

In thinking about whether we are meeting Rosenblatt’s call to action, I have a classroom story to share. Recently, I had the unexpected “pleasure” of having to teach two classes of students simultaneously after each had already had their primary science lessons for the day. One was a class of kindergartners and the other a class of second grade students. The second grade students had prior experience with the Knowledge and Knowing Study and were familiar with the KKS-IP so I asked if they would be interested in working with the kindergartners one-on-one. We decided they would plan questions meant to guide the kindergartners to make more detailed observations and help them practice generating as many descriptors as possible to express their thinking. Not only did they do that, they helped the kindergarten students improve their sketches and some even taught others how to make leaf rubbings. Near the end of the session, I asked the second graders to write down which teaching strategies they felt worked and what they wanted to try to improve before working with the next class of kindergarten students. I assisted the students in analyzing their data during the debriefing session because their lack of experience hindered them from noticing the relevance of some of the younger students’ replies. With guidance, students uncovered patterns in the younger students’ observations, questions, and challenges. I noticed they were starting to make distinctions between knowing and learning. In this session, the second graders expressed that the kindergarten students ‘knew’ something when they provided possible reasons for the conditions of the leaf, or they were able to identify the functions of particular parts of the leaf (stem) even if they did not know the name of the structure. They referred to learning as when the kindergarten students asked them questions and compared their leaves with other leaves because they were learning or trying to find out more about their own leaves.
Since starting to use the KKS protocols and the BBST framework (and modifications of them as shown in this example of the kindergarten and second grade students), I feel there is a new language spoken during our class time, in other subject areas, and even recess. This language translates into respect and a willingness to find out more about what they and others know, and also, for the ways in which they come to know about the world.
GLOSSARY

Activity—a system of human actions, interactions, and transactions whereby a subject (a person, team, or machine) works on an object (e.g., material object or problem-space) in order to obtain a desired outcome. In order to do this, the subject employs tools, which may be external (e.g., books, computers, equipment) or internal (e.g., concepts, plans, algorithms).

Being|becoming—this notation is inspired by Anna Stetsenko’s model of human development where becoming (or being) is the process by which individuals come to understand and transform the world and themselves by contributing to the world. In other words, changing one’s world, knowing one’s world, and being (or becoming) oneself are all part of a single continuous process. It is not possible to separate the lifelong process of human development into discrete stages or periods of knowing, being, and transformation. We use a “Scheffer stroke” ( | ) to indicate that being and becoming exist in a dialectic. That is, one always presupposes the other—we are always being and we are always becoming, and we cannot “be” unless we’ve “become,” and we cannot “become” unless we “are.”

Career scientist—refers to a person who earns a living wage by conducting scientific research. A career scientist might work for a colleague or university, a government department (e.g., Department of Environmental Protection, Institute for Educational Sciences), a science-rich cultural institution (e.g., museum, aquarium, or park), a for-profit company (e.g., pharmaceutical company, oil company), or a not-for-profit organization (e.g., World Wildlife Fund).

Collaborative transformative practice—refers to the practices people engage in when changing one’s world, knowing it, and being (or becoming) oneself in view of their goals. These practices always involve contribution because self-development and community development are types of contributions. Collaborative transformation practice refers to the endless, interconnected, and dynamic processes of being and becoming, knowing and learning, and transforming and changing oneself and one’s environment (e.g., Stetsenko and Arievitch, 2004).

Contribution—the meaning of contribution is a standard dictionary meaning, “anything given or furnished to a common stock, or towards bringing about a common result” (OED, 2014a). The emphasis here is on the fact that “people always do contribute to something that goes on in the world, even if only on a small scale, and even if by doing nothing (because the latter type of a ‘contribution’ often helps to perpetuate the existing status quo and to stifle changes in society)” (Stetsenko & Arievitch, 2004, p. 495). Teachers contribute to the world by creating safe and
inviting environments where students can learn about the world and contribute to the world. Through these actions of teaching and learning, children and teachers change the world and themselves as part of the world.

**Discipline perspective**—refers to the organization of science as well as the expectations for learning particular facts, skills, and norms relevant to the scientific enterprise. The discipline perspective typically represents science as a three-part structure, including the (1) body of knowledge in science, (2) methods and processes of generating knowledge in science, and (3) ways of knowing in science—or Nature of Science (NOS) and students are expected to learn canonical knowledge and practices in each of these areas.

**Everyday tools**—also referred to as everyday concepts or spontaneous concepts. Everyday tools refer to concepts (rules, norms, information, skills, etc.) that are based on intuitions and everyday experience (Bodrova & Leong, p. 210). They are the result of the generalization and internalization of everyday personal experience in the absence of systematic instruction (Karpov & Haywood 1998, p. 28).

**Human activity**—see Activity.

**Knowledge-acts**—instead of using the word knowledge or knowing to refer to the state of possessing facts and skills in our brains, we propose using the term knowledge-acts. This captures the reality that knowing and knowledge are shorthand for the action or the ability to take action with a particular tool for thinking or learning to pose, define, or solve a problem or do intellectual work (e.g., knowing means we can prove it, show it, explain it, make predictions) By thinking about acts of knowledge instead of facts of knowledge, the human activity is constantly made visible, that is, the actions of using tools for thinking to “collaboratively transform the past in view of the present conditions and future goals.” Knowledge-acts and tools for thinking are interdependent. Actions require tools for thinking, and tools for thinking arise from and are transmitted through action.

**Learner perspective**—refers to the questions and goals of science learners. It presumes the learner is interested in the world around her and is eager for ways to learn how to learn more about it. A learner perspective embodies the spirit of wonder and the desire to understand and explain, emotional-psychological states which are necessary to sustain scientific inquiry. In our interpretation of a learner perspective we recognize that the goals of any science learner are to learn how to enter the conversation of science now and in the future, conduct inquiry in the pursuit of credible information, and become a scientist. The phrase a learner perspective does not refer to observations or ideas about students’ particular interests or opinions (e.g., “Many students this age get excited about dinosaurs and outer space”; “Bella
is really interested in how weather forecasting works”; “Aiden has been collecting rocks and wants to know how volcanoes work”).

Learner–scientist—refers to anyone interested in science, including but not limited to students (e.g., K-12, college/university students), teachers, science teacher educators, citizen scientists, and career scientists.

Learning action—refers to “the actions students use to solve learning tasks. Examples of learning actions include framing the problem, general and specific strategies of solving the problem, monitoring, evaluating the results, and self-correction” (Bodrova & Leong, p. 210).

Object—in activity theory, the object refers to the problem-space or physical material on which the subject works. For example, a science object might be understanding how people are affecting the Earth’s resources, finding the cause of an infectious disease, or explaining the difference between inherited and acquired characteristics. (See object–motive.)

Object–motive—in activity theory, the subject (e.g., a student or teacher) works on an object, and this makes the object the motive of the activity. Usually motive is thought of as separate from the object. For example, we often refer to internal and external “motivators,” such as: students are motivated to learn by an engaging book or teacher, or they are motivated to please themselves or others. These portrayals disregard the notion that the motive is embedded in the selection of object. In other words, the object (e.g., understanding how people are impacting the Earth’s resources) is what motivates the activity. For example, if “pleasing others” is an actual motive for learning about the Earth’s resources, then the object of the activity is to please others by understanding how people are affecting the Earth’s resources. In activity theory, a motive is an object, material, or ideal that satisfies a need.

The Scientific Method—this refers to a common myth perpetuated in school science and science for the public. It is perpetuated by a variety of people, including science educators, career scientists, science teacher educators, science journalists, and science textbook authors. There is no single scientific method used by scientists. A variety of methods and processes are used in science to answer questions and test assumptions and hypotheses. Methods are fluid and dynamic guidelines that can never be repeated the same way twice by the same person or between people.

Theoretical tools—also referred to as scientific concepts. Theoretical tools refer to concepts (rules, norms, information, skills, etc.) reveal essential patterns, principles, and relationships that represent the generalization of the experience of humankind and that children are taught in the course of systematic instruction. Once scientific
concepts have been acquired and internalized by learners, they can be used to mediate student’s problem solving. (Karpov & Haywood, 1998, p. 28)

Tools for thinking—instead of using the word knowledge to refer to an object such as information, explanations, facts, ideas, laws, concepts, theories, schema, rules, norms, social practices, skills, and algorithms, we propose the using phrase tools for thinking. This is based on the work of the educational psychologist Lev Vygotsky, who explained higher mental functions (e.g., mediated perception, focused attention, deliberate memory, and logical thinking) are performed using tools and signs generated by people to accomplish these functions. Tools for thinking are dependent on knowledge-acts and vice versa.
APPENDICES

APPENDIX A

Transcription Conventions

Although conversation analysis was not performed in this study, excerpts were transcribed following adaptations of the conventions of the “Jefferson system” (ten Have, 1999, pp. 213–214).

Sequencing

=  An equals sign shows “latching,” that is, two utterances are not separated by a detectable pause.

Characteristics of speech production

—  A dash denotes a sharp cut-off of a prior word or sound.
.  A period indicates a natural ending and a stopping fall in tone.
,  A comma indicates a comma-like pause. It indicates continuing intonation such as when one reads items from a list.
?  A question mark indicates a rising intonation

Transcriber’s doubts and comments

((text)) Descriptions enclosed in brackets contain transcriber’s descriptions in addition to transcriptions.
[text] Transcriber’s assumption about a spoken word or phrase
text Text formatted in italic highlights utterances discussed in the interpretation
APPENDICES

APPENDIX B

Interview Protocol: For a study of the meaning of the word scientist

Interviewer: There are no right answers. We are trying to learn more about people’s perceptions of scientists. It’s really important to say what you think.

1. This is one definition of scientist we found in the Oxford English Dictionary:
   “A person who conducts scientific research or investigation; an expert in or student of science, especially one or more of the natural or physical sciences”. Do you agree with this definition? Why or why not?

2. Can you think of anything to add or anything you’d like to change about the definition?

3. How are you like a scientist?

4. If you don’t think of yourself as a scientist, why not?

5. What do you think scientists do that you don’t do?

6. A career scientist is someone who earns a living or salary as a scientist. I have three questions to ask you about career scientists.
   a. Who do you think can be a career scientist? Why?

   b. Who do you think cannot be a career scientist? Why not?

   c. Do you think career scientists are similar or different from non-career scientists? Why or why not?

APPENDIX C

*Media Analysis Guide:* How the authors of the science books and magazines in my/our library represent scientists (*can be used for any media source type*).

Book Title: ____________________________________________
Book Author: ___________________________ Publication Date: ____________
Research Associate: ______________________ Analysis Date: ________________

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<th>A Few examples</th>
<th>Many examples</th>
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<td></td>
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<tr>
<td>Anonymous scientist (“the scientist …” or “scientists say …”)</td>
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<td>Real scientist with a name</td>
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<td>Working with a group</td>
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Additional Comments

APPENDICES

APPENDIX D

Interview Protocol: A study of the science experiences of our elders

Interviewer: Some research with students our age shows that when we draw pictures of scientists we usually draw white men in lab coats working in indoor laboratories. We are studying whether or not our elders (our parents, grandparents, aunts and/or uncles) have ever experienced discrimination that might make them think they were not good at science or that science wasn’t for them. Would you talk to me about your experiences in school science? [If the RA you ask agrees to an interview, then ask the following questions.]

1. What do you remember of elementary school science?

2. Did you like elementary school science?

3. Could you describe any adult scientists (fictional or real) featured in TV, books, or films you enjoyed?

4. Could you describe any child/youth scientists (fictional or real) featured in TV, books, or films you enjoyed?

5. Did you ever think you were not good at science?

6. Did you ever think science wasn’t for you?

7. Did anyone ever tell you that you couldn’t be a scientist?

Other reflections:


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APPENDICES

APPENDIX E

A digest of the educational background of each author on the Next Generation Science Standards writing team as described on the nextgenscience.org website. Refer to the individual biographical sketches on the website for more detailed information about awards and additional positions held by each author.

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<td></td>
<td>MS—Curriculum and Instruction, Mankato State University</td>
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<td></td>
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<td></td>
<td>MS—Elementary Education, Northern Illinois University</td>
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<td></td>
<td>MA—Science Education (in progress)</td>
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<td>National Board Certification—Early Adolescence Science</td>
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<td></td>
<td>Elementary Math and Science Teacher and STEM Coordinator, Bowie, MD</td>
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<td>High School Science Teacher, Washington, DC</td>
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<td>Science and Music Curriculum Director, Orland Park, IL</td>
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<td>Assistant Principal, Carrollton, GA</td>
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<td>MA—Physiology, Texas Tech</td>
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<td>Director of Science and Technology/Engineering, Massachusetts Department of</td>
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<td>Science Education Consultant, Forks, WA</td>
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<td>BS—Zoology, University of Washington MA—Curriculum and Instruction, Lesley University Certification—Secondary Science</td>
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<td>Career Scientists (with college science teaching experience and science education research experience)</td>
<td>Professor of Physics, Arlington, TX BA—Physics, University of Illinois at Urbana-Champaign MA—Space Physics, Rice University PhD—Space Physics, Rice University</td>
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<td>Career Science Education Researchers (most with classroom teaching experience)</td>
<td>Associate Professor of Earth and Planetary Sciences, St. Louis, MO BS—Geophysics, Brown University PhD—Geophysics, Northwestern University</td>
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<td><strong>BS—Guidance and counseling, Long Island University</strong></td>
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<td><strong>PhD—Earth and Environmental Sciences, City University of New York</strong></td>
<td><strong>Career Education Researchers (interdisciplinary)</strong></td>
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<td><strong>Professor, Science Education and Diversity and Equity, New York, NY</strong></td>
<td><strong>BA—English, Kyungpook National University</strong></td>
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<td><strong>MA—Educational Psychology, Kyungpook National University</strong></td>
<td><strong>PhD—Educational Psychology, Michigan State University</strong></td>
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<td><strong>Certification—TEFL (teaching English as a foreign language in secondary school), Kyungpook National University</strong></td>
<td><strong>Business Leaders (includes educational consulting companies and STEM industries)</strong></td>
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<td><strong>Director of Field Impact, Student Achievement Partners, New York, NY</strong></td>
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<td><strong>MA, PhD/ED—Educational Leadership, Rowan University</strong></td>
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<td><strong>Westbrook Consulting Services, Austin, TX</strong></td>
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<td><strong>MET—Science, Math, Technology Education</strong></td>
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APPENDIX G

Media Analysis Guide—How a source represents scientific problems

Topic:
Title:
Author:
Publisher:
Publication Date:

1. How is _________ defined?

2. What tools for thinking about ________ are presented?

3. What historical or contemporary scientists are featured, if any?
   a. How many were men?
   b. How many were women?

4. How are children represented (e.g., boys vs. girls, conducting investigations vs. narrating facts)?

5. How were men and boys depicted in images or photos in the book, and what were they doing?

6. How were women and girls depicted in images or photos in the book, and what were they doing?

7. What connections are made between:
   a. Past theories and contemporary theories?
   b. Explanations and everyday phenomena?
APPENDICES

c. Phenomena and models?
d. Contemporary problem posing?

8. Are models misrepresented as discoveries or are they, more appropriately, represented as syntheses created by people?

9. What tools for thinking about science are promoted (e.g., anyone can contribute or only experts can contribute, it’s anonymous or it’s the work of real people)?

10. Is a single story presented, or multiple stories?

REFERENCES


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REFERENCES


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ABOUT THE AUTHORS

Susan A. Kirch is an Associate Professor of Science and Childhood Education at New York University in the Department of Teaching and Learning. In 2012 Kirch was recognized by the Steinhardt School for a Teaching Excellence Award for her work preparing elementary science teachers for teaching science as well as doctoral candidates who are interested in science education systems more broadly. Prior to becoming a science teacher educator Kirch began her career at Mount Holyoke College, then Harvard and UCSF as a molecular biologist working with mentors and colleagues in evolutionary molecular biology, immunology, and developmental neuro-genetics to publish articles in Science, Development, and Proceedings of the National Academy of Sciences, among others. After participating in a variety of initiatives designed to bring teachers, K-12 students, educational researchers, and scientists together to study access to science, Kirch was inspired to switch her research focus from the biological sciences to science education. Since then the partnership with Amoroso has become an unparalleled space for idea generation, critical science curriculum production, and collaborative exploration with children, which have fueled her interests in how learner-scientists contribute to scientific knowledge creation as well as understanding the reconstruction of process-tools such as evidence, causality and relevance in school classrooms. Kirch is particularly curious about the nature of scientific inquiry that all students experience in and out of formal school contexts. In 2008 (with Anna Stetsenko and Catherine Milne), she received a National Science Foundation award to study how children experience the concept of evidence. She has published chapters and articles with colleagues in education on school funding, inclusion, feminist pedagogy, curriculum, evidence and knowledge production, and the production and resolution of uncertainty in science and science classrooms. This book with Michele Amoroso is her first.
ABOUT THE AUTHORS

Michele Amoroso is a native of Queens, New York. She has been a New York City public school teacher in her community for twenty years. Amoroso worked days as a hairdresser while she attended night school to eventually obtain certificates in early childhood and childhood education, administration and supervision, and a master’s of science in elementary education. Since then Amoroso has taught early literacy, math, social studies and science and always strives to create rich contexts for learning through taking socio-cultural approaches to curriculum development and instruction. She continues that approach in her current position as a prekindergarten through third grade science teacher for approximately 300 young learner-scientists who rely on her for learning in all fields of science. Amoroso’s desire to be a teacher-researcher was realized when she met Kirch at a routine professional development workshop. Everything but routine, their decade-long research collaborative is detailed in this book and continues to powerfully transform her current practice as an elementary school science teacher. This research collaboration also informs her work in teacher education as an adjunct lecturer in the areas of science, mathematics, and literacy education at her alma mater Queens College, CUNY. Amoroso has presented her research at several education conferences including those sponsored by the National Association of Research in Science Teaching and the Association of Science Teacher Educators organizations. She is also the author of a handbook chapter demonstrating the development of an Earth and space science lesson for an early childhood audience. Her future work with Kirch will likely expand on the work reported here. This book with Susan Kirch is her first.
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