Being and Becoming Scientists Today
Reconstructing Assumptions about Science and Science Education to Reclaim a Learner–Scientist Perspective

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- Can I contribute to science?
- Do I like to work on the problems of science?
- How do scientists know what they know?
- Would I like to become a scientist?

These are questions that interest new science students.

The authors provide teachers with an approach to foster and answer these questions by concentrating on learners and learning. They argue that students are typically taught from a disciplinary perspective of science. Using this lens students are viewed as people who need to learn a particular canon of information, methods, and ways of knowing about the world—a perspective that may be useful for practicing scientists, but not ideal for young learners. In this disciplinary approach to science education there is little room for development as a scientist. In contrast, the approach championed by Kirch and Amoroso places learner questions about the world at the forefront of teaching and learning and treats science as a system of human activity.

The historical explorations, theoretical insights and practical advice presented here are appropriate for all ages and educational settings. In Being and Becoming Scientists Today, the authors provide: new tools for thinking about science, ideas for how to reveal the multiple stories of knowledge production to learners, and approaches to teaching science as a collective process rather than a series of contributions made by (famous) individuals. In these ways, the authors promote the idea that all science learners contribute to the science in our lives.

Being and Becoming Scientists Today
CULTURAL AND HISTORICAL PERSPECTIVES ON SCIENCE EDUCATION:
RESEARCH DIALOGS

Volume 7

Series Editors

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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.
Being and Becoming Scientists Today

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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.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Acknowledgments</th>
<th>ix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>xi</td>
</tr>
<tr>
<td>Chapter 1: Rethinking Science Education from a Learner Perspective: A Framework for Being and Becoming Scientists Today</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Science as a System of Human Activity</td>
</tr>
<tr>
<td></td>
<td>Conclusion</td>
</tr>
<tr>
<td>Chapter 2: Being and Becoming Scientists: What Does It Mean to Be</td>
<td>Become a Scientist? Who Can Be</td>
</tr>
<tr>
<td></td>
<td>It’s Always Time to Challenge and Reconstruct Ideals</td>
</tr>
<tr>
<td></td>
<td>Who Can Be</td>
</tr>
<tr>
<td></td>
<td>Inquiry Projects and Tools to Support Being</td>
</tr>
<tr>
<td></td>
<td>Contribution</td>
</tr>
<tr>
<td></td>
<td>Conclusion</td>
</tr>
<tr>
<td></td>
<td>Topic: Energy Concept</td>
</tr>
<tr>
<td></td>
<td>A New Lens for Instructional Planning and Curriculum Review</td>
</tr>
<tr>
<td></td>
<td>Conclusion</td>
</tr>
<tr>
<td>Chapter 5: Classroom Results from a Knowledge and Knowing Study: How Do I Know What I Know? How Do Scientists Know What They Know?</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Establishing Student-Centered Research Activities in Daily Instruction with the KKS Study</td>
</tr>
<tr>
<td></td>
<td>Conclusion</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

Our Stories: Our Stories of Being/Becoming Educators and Learner–Scientists and of How We Met 189

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 193

Glossary 201

Appendices 205

References 217

About the Authors 223

Name Index 225

Subject Index 229
ACKNOWLEDGMENTS

We have been working together, co-teaching and conducting research, since 2003. In that time we have accumulated a number of people and funding agencies to thank.

First, thanks to Ken Tobin for inviting us to write this book for Sense. His recognition and support have been invaluable. Since the first invitation we have had the pleasure to work with Michel Lokhorst, Catherine Milne, and Kate Scantlebury and we are honored by their commitment to seeing this work published. We are especially grateful to Catherine Milne who offered superb editorial expertise above and beyond her typical responsibilities.

We are indebted to the efforts of Moshe Sadofsky who was willing to do everything from identifying run-on sentences and fact-checking science content statements to engaging in philosophical discussions about the nature of being and becoming a scientist. The notion of energy as an accounting tool emerged from one of many discussions about energy and is credited to Moshe. To ease our fears about grossly misusing the comma and our perceived inability to identify various errors of style, we hired Jennifer DePrima for copyediting and we feel lucky to have found her through our contact at Guilford Press. Even with the help of these careful readers, we assume all responsibility for any errors of grammar, fact or style readers may discover.

We are indebted to all the students, teachers, parents, principals, and school staff who have worked with us over the years as part of various data-intensive research projects including, but not limited to: Tara Clark, Kerry Decker, Margarita Dhandari, Jaime Disken, Laura Ingram, Helene Jacob, William Kong, Sabine Kullman, Ian Lambert, Vivecca Lamourt, Sari Marder, Adrienne Mehan, Shara Miller, Ariel Ricciardi, Audrey Schmuel, Anastasia Schneider, Patti Scotti, Ilene Silverman, Rebecca Terrigno, Kaya Wielopoloski, and Cecilia Wong. In the midst of their busy school lives they were willing to actively participate in various aspects of the research associated with this work. For some, that included discussions and classroom observation and for others that included allowing us to record classroom events and interviews for further analysis. Those recordings made it possible for us to ground this work in real-world classroom life and feel confident that we were representing the contributions of participants accurately.

We are grateful for financial support from various sources including: the Professional Staff Congress of the City University of New York (PSC-CUNY 38 to SK), Steinhardt School of New York University (IDEA Grant 2008 to SK), New York University (Research Challenge Fund 2008 to SK), and support to SK and MA from Kenneth Tobin (National Science Foundation Distinguished Teaching Scholar Award, 2004-2006 to KT). The data from the Knowledge and Knowing Study presented in Chapter 5 was the result of work undertaken by SK as part of the Scientific Thinker
ACKNOWLEDGMENTS

Project (STP) and was funded by the National Science Foundation (Principal Investigator, Susan Kirch; coPIs, Anna Stetsenko and Catherine Milne; DRL 0918533). (Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the view of any of the granting agencies or bodies). Sue specifically thanks the entire STP research team, and is especially grateful for the hard work and dedication of the research assistants and associates who worked during the project’s development (unfunded) period (Sanaz Farhangi and Christine Robertson) and during the implementation (funded) period (Kara Naidoo, Ranyee Chiang, and Laura Paskell-Brown). Special thanks go to Anna Stetsenko for her intellectual insights, curiosity and support in addition to brainstorming BBST. Michele thanks the team for recruiting her as a member of the advisory board.

Finally, we’d like to thank our family and friends whose unending supply of encouraging words and confidence in us ensured that the darkest days of writing always had a nightlight. Sue is thankful for: Moshe Sadofsky, Penny Colman, Linda Hickson, Rudolph “Rudy” Kirch, Frank and Charlotte Sadofsky, David and Teddi Baggins, Lynne Spevack, Michele, and the encouragement of her Mount Holyoke College chums. Michele is grateful to: Teresa, Phil, John, and Joe D’Amico, Kenny Zornmueller, her teachers, co-teachers Sue and Moshe and her parents.
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
INTRODUCTION

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
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
INTRODUCTION

col-ed 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.

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](figure)

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 become 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/becoming 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/becoming scientists 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

<table>
<thead>
<tr>
<th>Core aspect</th>
<th>Education from perspective of discipline</th>
<th>Education from perspective of learner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body of knowledge</td>
<td>Students should learn the canonical</td>
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<td>explanations for natural phenomena</td>
<td>Would I like to become a scientist?</td>
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<td>How am I like a scientist today?</td>
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<td>What do scientists know, and how did they come to know it?</td>
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<td>How does one contribute to scientific knowledge?</td>
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<td></td>
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<td>What is scientific knowledge?</td>
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<td></td>
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<td>Do I like to work on scientific problems?</td>
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<td>Methods and processes</td>
<td>Students should learn that scientists</td>
<td>Would I like to become a scientist?</td>
</tr>
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<td>use various methods when they do their research and should practice the methods used by scientists today.</td>
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<td>How does one contribute to scientific knowledge?</td>
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<td>Do I like to work on scientific problems?</td>
</tr>
<tr>
<td>Nature of scientific knowledge</td>
<td>Students should learn that scientific knowledge produced by scientists today has particular characteristics and why.</td>
<td>How do scientists come to know what they know?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How do I come to know what I know?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How does one contribute to scientific knowledge?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Do I like to work on scientific problems?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>What is scientific knowledge?</td>
</tr>
</tbody>
</table>

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
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.
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? 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? 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? How do scientists foster creativity? 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? 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? How do we describe patterns we see in nature? 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? What science does the public (the government) fund? Who decides what phenomena in the natural environment we are allowed to study? 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):
CHAPTER 1

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).

Figure 1.4a. Science and science education viewed as interconnected human activities

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
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).

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.

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?