The Journey From Child to Scientist

Integrating Cognitive Development and the Education Sciences

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Moving Young "Scientists-in-Waiting" Onto Science Learning Pathways: Focus on Observation

Rochel Gelman and Kimberly Brenneman

> It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories instead of theories to suit fact.
> —Sir Arthur Conan Doyle, *A Scandal in Bohemia* (1891/1985)

The growing crescendo from schools, industry, government, and even the President of the United States presses academic researchers to provide ways to upgrade students' scientific literacies. This widespread push is motivated by the everyday demands we face in our increasingly technological society. We are confronted regularly with discussions of genetic engineering and its potential for reducing the risk of disease and improving the quality and quantity of food sources; statistical reports on the risks and benefits of pharmaceuticals; the need to interpret very, very large budget numbers and probabilistic statements about the outcome of economic policies or the interest charges on credit cards and bank accounts; and so on. No longer are these challenges for people with specialized training or education alone. More and more, they are simply skills that all citizens must have to evaluate the flow of information they encounter every day. Furthermore, jobs that require technical and scientific skills remain unfilled because of a lack of preparation of the workforce, and jobs that do not have such requirements are disappearing. For these reasons, identifying ways to improve scientific and technological literacy constitutes a critical research and educational agenda.

In this chapter, we join those who argue that it is a good idea to introduce young children to STEM (science, technology, engineering, and mathematics) topics and methods even during the preschool years (Bowman, Donovan, & Burns, 2001; Duschl, Schweingruber, & Shouse, 2006). First, there exists a cumulative research base with preschool-age, and even younger, children that documents their knowledge about causality; natural number arithmetic; and some of the principled ways in which animals, plants, and inert objects move and change over time (Bowman et al., 2001; Carey, 2009; Duschl et al., 2006;

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Gelman & Williams, 1998; Gopnik, Meltzoff, & Kuhl, 1999). Because these arenas of knowledge overlap with science domains, we and our colleagues expected that we could build from young children's competencies and create a program of appropriate learning options that would hold their attention and support them to build knowledge about science and its tools (Gelman, Brenneman, Macdonald, & Roman, 2009).

By choosing to work with children's relevant foundational knowledge, as well as their natural proclivities to explore and ask questions (Callanan & Oakes, 1992; Chouinard, 2007; Frazier, Gelman, & Wellman, 2009) and to try to make sense of the world around them (e.g., Schulz & Bonawitz, 2007), we have avoided a push-down curriculum made up of interesting facts that could not be explained in a way the children would understand. For example, we know of a program for kindergarteners that taught children that they would weigh less if they were on the moon. One of our (Rochel Gelman) friend's children was most eager to tell about this fact. When asked by an adult, "Would you weigh more when you come back to earth?" the child's immediate response was "Yes," but then she turned and said, "This doesn't make any sense," and left. Fortunately, she did not ask for an explanation, because the adult surely did not know the relevant physics. This paucity of knowledge was likely to have been the case for the child's kindergarten teacher as well; many adults have trouble understanding the physics involved in the account of this fact (McCloskey, 1983; McCloskey, Caramazza, & Green, 1980). Indeed, elementary and preschool teachers frequently report discomfort with their knowledge of science and their ability to incorporate it appropriately into the early education classroom (e.g., Greenfield et al., 2009). Basing our preschool science program on concepts that can be effectively explained to preschoolers has increased teachers' comfort level and feelings of competence with teaching science. After all, the program takes advantage of the reported competencies of their young charges.

Some Reminders

It is no longer assumed that young children learn whatever is in their environment, as if their minds were receptacles into which knowledge is poured. They, like all learners, often are active participants in their own learning. Second, it is a characteristic of human cognition that learners' attention is more likely to focus on inputs that can be related to already-existing knowledge and or beliefs. One's knowledge and beliefs influence how one interprets the environment. This is as true early in one's life as it is later. A poignant example comes from Vallone, Ross, and Lepper (1985), who showed a common news clip to groups of Israelis and Palestinians. Both groups contended that the report was biased against them. This is but one example of what is dubbed the *confirmation bias* in the social psychology literature. Failure to pose an alternative hypothesis and consider the evidence permeates our everyday lives.

A second example illustrates that the information that captures attention is related to what one already knows. Yoshida, Fernandez, and Stigler (1993) showed the same section of a videotaped math lesson to fourth graders in the United States and Japan and asked the students to describe it. The U.S. students tended to talk about nonmathematical items, including what the teacher was wearing, whereas Japanese students' comments focused on the mathematics in the lesson and revealed a deeper degree of understanding. The knowledge that they already possessed supported greater attention to mathematical information and further learning.

Details related to this particular example offer clues about the nature of environments that may support learning. To be sure, the differences between the two groups of students in Yoshida et al.'s (1993) study included a constellation of interrelated variables that reflect deep cultural differences, for example, the relative homogeneity of the Japanese students in a class. Still, some of these variables are worthy of attention in regard to any effort to teach mathematics. Japanese teachers of elementary school children know more mathematics, spend more time teaching a more organized mathematics lesson, and encourage their students to relate homework to lessons as well as successive lessons to each other (Stevenson & Stigler, 1992; Stigler & Hiebert, 1999). Put differently, Japanese students have more opportunities to assimilate material, to try to talk about it, and to consider alternative solutions. They also have teachers who know enough to nudge their pupils who make errors to consider another direction.

There are many other examples of how knowledge or the lack of knowledge influences what learners focus on in any potential learning situation (see Bransford, Brown, & Cocking, 1999). The foregoing particular result from Yoshida et al. (1993) is especially relevant for the discussion of possible STEM educational programs. From a pedagogical perspective, it illustrates the kinds of variables that have been identified as relevant for the design of teaching methods:

- Learners are more likely to attend to and assimilate inputs if these can be related to existing knowledge organizations.
- It helps to have the learners involved in the creation of and communication about possible solutions or answer paths.
- When the goal is to build understanding, as opposed to learning facts and algorithms, it takes a considerable amount of time on task.
- Learning about a domain is facilitated when knowledgeable individuals present different examples about the main or big ideas of the subject at hand. Put differently, when inputs are organized in terms of the principles that underlie the examples, the odds favor the acquisition of understanding even if the surface details of the exemplars vary (Richland, Zur, & Holyoak, 2007).
- Procedures and concepts are intricately linked (Gelman & Greeno, 1989; Lampert, 1986). When it comes to the topic of science, content and science practices naturally and necessarily go together (Duschl et al., 2006; Kuhn, 1962).

Science as a Domain

What does it mean to do, learn, or teach science? It does not mean to master or offer a list of facts and definitions of technical terms. Neither is it sufficient to merely teach about the experimental method. Engaging in science practices, such as observing or predicting, requires a focus on content. One needs something to observe and events to predict. Furthermore, the language that is relevant to the concepts in a given domain is closely related to the concepts therein, and the more one knows about a domain, the deeper the understanding of the language in that domain (Bransford et al., 1999; Carey, 2009). Different domains of knowledge build on different kinds of content from different sources. Likewise, the principles that organize domains vary. To illustrate, in the next few paragraphs we consider how the domain of history differs from that of science.

Historians reconstruct the past. They rely on written documents, artifacts, land arrangements, and art from a given time period, but they cannot be sure that they have all the relevant documentation from that time. In addition, there can be disputes as to what some documents record, especially when historians work in a language that has disappeared. The starting assumptions can have a profound effect on the resulting product. In point of fact, historians in different countries have, and still do, provide different accounts of the same period of time. The discovery of new documents from the past can have an enormous impact on what becomes accepted as knowledge of the past.

Scientists, in contrast, are concerned with explaining the natural world. Topics include the objects on, in, and surrounding the earth; the states and changes of these objects; the energy conditions that influence matter; the organization and function of biological matter; the nature of inert entities; laws of motion; and how entities interact with their ecological niches, as well as many other topics. Experiments and their related procedures provide the relevant data for explanations. Notebooks (or computer files) are used to keep track of theoretical motivations, design concerns, observed data and their organization, the results of various conditions, and further hypotheses and ideas for new explorations. Different branches of science focus on particular topics, but all assume that the to-be-found laws are universal and organized in coherent ways and that the findings and generalizations flow from the use of experimental and modeling methods. When students learn science, all of these factors come into play, and all are incorporated into the educational programs that have been developed to study and foster science learning in real-world settings. Regardless of the specific branch of science, there is a fundamental commitment to the role of observations as the source of data, be it to obtain initial evidence about a phenomenon or to test a theory. New observations that are reliable and open to inspection by others can drive major shifts in what are taken as the basic facts to explain through theory.

On Scientific Observations

To do science today is to ask about the natural phenomena in the world and do so in a systematic way, using the methodological, physical, and even mathematical tools of the discipline. In turn, the tools build on fundamental commitments to gather repeatable, observable data. This recognition of the central role of observation is relatively new in our history. "The man who first taught that observations are essential and supreme in science was Galileo Galilei" (Cropper, 2001, p. 3). The history of science also details the important role of instruments that enhanced observational powers, including the microscope, barometer, thermometer, computer, scale, ruler, graduated cylinder, clock, telescope, and other items. So too are there history lessons about the role of the observer's background knowledge and access to tools that make observable what cannot be seen by the naked eye.

Galileo (1564–1642) provided an early example of the interaction among one's observations, hypotheses, and prior knowledge. He was trained in the art of drawing, an advantage when he used his telescope to record his observations of the surface of the moon. Galileo knew that the shading of light and its reflections could be due to depths and shapes, from which he correctly concluded that there were mountains and craters on the moon. His other observations of the sun and Jupiter contributed to his move to endorse Copernicus' proposal that the earth rotated around the sun. Doing so landed him in very serious trouble with the Roman Catholic Church, which held that the earth was the center of the universe and, therefore, that the sun rotated around the earth. The Church's view that the sun and the moon were perfectly smooth also clashed with Galileo's observations to the contrary (Cropper, 2001).

The critical idea that Galileo gave us is that our senses provide information about the world. Another critical idea is that one cannot count on gaining all relevant observations from the surfaces of an object. Often it is necessary to make a prediction about the insides and then proceed to investigate. The work of Vesalius (1514–1546), an anatomist, provides a lovely example of this theme.

Apparently, it never occurred to anyone before Vesalius to do a thorough dissection of a human body in conjunction with a very careful set of observations (Cropper, 2001). So strong was the authority of the ancient writers that surgeons and physicians were taught what Galen (130–200) claimed were the facts of anatomy for 1,500 years after his death. The results of the Vesalius dissection and its documentation made it clear that Galen was wrong in many ways. For example, Galen's description of human anatomy had the arteries in the left ventricle of the heart carrying the purest blood to the brain and lungs and the veins in the right ventricle carrying blood to the stomach and liver. He also concluded that there are two bones in the human jaw. In fact, Vesalius correctly determined that there is but one jawbone (Cropper, 2001). William Harvey (1578–1657) also helped establish the importance of direct observation with his detailed and experimental observations that established knowledge about the circulation of blood.

In astronomy, Tycho Brahe (1546–1601) became known for the care and precision of his observations of planetary motion, as did his famous assistant, Johannes Kepler (1571–1630), who realized that the correct mathematical description of planetary motion about the sun was that it was elliptical and that planets swept out equal areas in equal amounts of time (Cropper, 2001). Francis Bacon (1561–1626) also emphasized the importance of systematic observation in the acquisition of evidence-based knowledge, and by the middle of the 17th century the importance of observations was widely accepted by the leading scientists of the day (Cropper, 2001).

In the 21st century, many of the accepted observational tools have become extremely expensive. Physicists depend on accelerators; astronomers require better and better telescopes and cameras; doctors and neuroscientists have become wedded to ultrasound, functional magnetic resonance imaging machines; and the list goes on and on. A public that has a better understanding of the scientific view of observations and devices that enable their collection of data would be better able to engage in cost–benefit analyses.

As discussed above, the observational tools of science serve investigators who collect information about the world, its contents, and surrounds. These tools are used to extend observational power and gather information that is be relevant to a hypothesis, a prediction, or an experiment about the nature of the world. In addition to physical science tools, there are methodological tools that depend on observation. These include recording and dating one's observations in a way that others can read, predicting and checking, measuring, reporting, comparing and contrasting, designing and interpreting experiments, and others. In our work, we have found that these science tools can be introduced to young learners in a way that extends their natural proclivities and puts them on constructive learning pathways for school science.

On Building Up in a Preschool Science "Curriculum"

When it comes to the topic of early science knowledge and reasoning, we and other researchers have demonstrated that preschool children can learn quite a bit about some areas of science and arithmetic, without the kind of formal instruction that occurs in schools. They do so pretty much on the fly as they interact with their environment and knowledgeable others. The domains include arithmetic with a range of natural numbers, physical and social causality, the nature of the inanimate–animate distinction, and some knowledge about chemical and physical features of materials (Bowman et al., 2001; Carey, 2009; Duschl et al., 2006; Gelman & Williams, 1998).

Young children have natural habits of mind that stand them in good stead as "scientists-in-waiting." Even as they are just learning language, they select objects and events in the world—initially by pointing, and then with language—and seek to share their observations and/or to gather more information about these phenomena through referential pointing and shared gaze (Tomasello, 1995). They ask questions about things in the world and how they work or fail to work. Chouinard's (2007) analyses of four children's transcripts in the Child Language Data Exchange System database (see http://childes.psy.cmu.edu/) uncovered the fact that information-seeking questions occurred at the amazing rate of 76 per hour. Keep in mind that some children were not even 2 years old, an age at which they do not have much productive syntax. This calls to mind one of our sons crawling up the stairs in the house asking "What's this?" The reply—a stair—did not suffice. He asked the same question over and over and over again, day after day. Then one day he stopped asking the question. This sort of thing happens repeatedly: Children use questions as they seek not just to label the world but also to explain what they have observed and the patterns they have noticed (Callanan & Oakes, 1992; Chouinard, 2007; Frazier et al., 2009).

Children often play with the same objects over and over again and eventually know a great deal about their properties, such as whether they will float, balance, or roll smoothly. In their now-classic paper, Karmiloff-Smith and Inhelder (1974) reported on young children's persistent efforts to balance blocks. One of the blocks had a piece of lead, offset from the center. Children got to the point where they placed all of the blocks at their midpoint and labeled the off-center block as "no good." They set it aside but finally made a new effort to balance all of the blocks. Again, the trick block presented a problem. With repeated trials, the "no good" block attracted attention, a development that led to success. The block was moved back and forth across another block until it did balance. This set in motion a new theory of balance that explained their observations and placements of all of the blocks. Together, children's competence and knowledge about some of the content of science domains and their tendencies to observe and explain can be used in the development of coherent science curriculum for preschool. It takes more than these to be a scientist, though. Like David Klahr, we are skeptical about the idea that children will always, on their own, learn to formulate questions, use the experimental method, and generate explanations that consider the laws of science and the logic of scientific inquiry. Indeed, we doubt that many adults do this in their daily lives. In a sense, then, it is not just young children who are scientists-in-waiting—so too is a large majority of the U.S. population. We join other researchers in this volume in efforts to develop instructional materials that will move more children from child to scientist, in an effort to support a more scientifically literate citizenry.

Preschool Pathways to Science

Many of the physical and methodological tools of science can be reasonably introduced to even very young learners. For more than a decade, we have worked to develop the Preschool Pathways to Science (PrePS) program, which leverages children's natural curiosity, spontaneous exploration, and explanation-seeking activities (e.g., Callanan & Oakes, 1992; Chouinard, 2007; Jirout, 2009; Karmiloff-Smith & Inhelder, 1974/5; Schulz & Bonawitz, 2007) about some science concepts to create a program to support preschool science learning. Given changes in views of the preschool mind from descriptions of its deficits to a focus on its competence, we believed the time was ripe to develop an educational program that built on science-relevant conceptual competencies and habits of mind identified by cognitive developmental science. The idea was to move children onto relevant learning paths for the science they would encounter in elementary school but to do so in a way that was deeply rooted in cognitive science. In taking on this challenge, we joined Klahr and others who have attempted to bring together education and cognitive science as "beacons of mutual illumination" (Klahr, Chen, & Toth, 2001).

The content areas chosen for exploration in the PrePS program come from children's own interests and, critically, from competencies that preschoolers already have in science-relevant domains. The conceptual content is explored fully over time instead of moving rapidly from one idea to another. Children might study various aspects of *change* or *form and function* for months. This feature of the program reflects research showing that multiple opportunities to work with, think about, experiment with, and communicate about similar conceptual content in multiple, varied ways maximize the probability that students will attend to at least some of the offered lessons in the manner intended by the teachers. It also reflects an aspect of the constructivist mind; it is easier to learn more about something one already knows a bit about (Bransford et al., 1999).

In the PrePS approach to science education, content matters, and so too does the way content is presented; however, teaching children content without having them engage in science practices makes science seem like a list of facts and subtly reinforces the idea that science is something that *other* people do and think about (Gelman et al., 2009). Our goal with PrePS is to encourage all children to move from being scientists-in-waiting to becoming scientific thinkers by allowing them to wonder, explore, and investigate big conceptual ideas using the same science practices used by older scientists. Together, the conceptual–language side and the practice–tool side form a coherent approach to how science is characterized and implemented.

Children in the PrePS program are encouraged to think, talk, and work scientifically as a way to develop understanding. These practices are interdependent. Students who are observing, predicting, and checking are also learning the vocabulary words to describe these actions. In our work with preschoolers, we focus on five key science practices used to describe ways of thinking and doing science:

- observe, predict, and check;
- compare, contrast, and experiment;
- relate vocabulary, discourse, and language;
- count, measure, and other mathematics; and
- record and document.

Each practice is thought of as a group of related skills. Of course, in the end, all of the skills can be related to one other.

Building Observation Skills

In the following paragraphs, we focus in particular on efforts to develop children's understanding of observation. Given its fundamental role in science and in many other science practices, we introduce observation early in the program, use it repeatedly, and expand its use throughout the school year. Children come to think differently about an item that they are observing instead of just glancing at (Gelman & Brenneman, 2004).

For many years, we have introduced 3- to 5-year-old children to the idea of observation using an apple. During group time, the teacher provides an apple for each child, or passes around one apple. She or he introduces the term *observation* and explains that making an observation is noticing something about the apple: how it looks, feels, smells, sounds, or even tastes. (Children are told that tasting will come later.) Then the teacher asks children to share something that they notice about the apple as the fruit is passed. Children's observations (e.g., "It looks red," "It smells sweet," "It's cold") are written down by the teacher, aide, or another adult. In these early experiences, children's participation is more important than accuracy. For example, if a child says, "The apple smells juicy," the teacher does not correct that statement and instead probes meaning by asking, for example, "It smells juicy? What does juice smell like?"

In the next, related learning experience, children are introduced to the idea of *prediction* and are encouraged to make predictions about what they would observe inside an apple. Children's ideas are written down so that these can be referenced as the apple is cut to check children's predictions. Again, children make observations of the inside of the apple (e.g., "It's wet," "It's white and a little bit green," "There are five seeds!"). Checking their predictions provides more evidence of the critical role that observation plays in scientific exploration.

Watching a video of a class observing an apple for the first time is striking because the children attend so carefully to the task. Over the years, adults who have watched this activity have remarked that the children acted as if they had never seen an apple before. They had *seen* apples before, of course, but they had not *observed* them. The introduction of a new science term and practice transformed a familiar apple into an object for scientific exploration and allowed students to consider this common, everyday object in a new, more focused, way (Gelman & Brenneman, 2004).

In subsequent activities, we progress to making observations about other, less familiar items, and as we do so we very intentionally begin to have children link the observations they make to their senses, or the sources of the information that they are gathering. For example, one activity involves a coconut, which is a great item for illustrating that one can make many different observations about the same object or event. Children describe the coconut and practice linking each of their observations to a particular sense as the source of the information: brown, hairy like a lion, round, has circles on the end (eyes); rough, hairy (skin); juice inside (ears); smells like dirt, smells yucky (nose); heavy (muscles). In a recent visit to a classroom, children begged to eat the coconut to make observations about its taste and texture. Their reviews were uniformly negative. The coconut was "not good" and tasted "yucky," but we remain impressed by their curiosity and spirit of exploration.

These introductory activities lay a foundation for a more in-depth exploration of observation and senses. Adapted from the work of our colleagues Christine Massey and Zipora Roth with K–1 learners, the activities go beyond matching body parts (e.g., eyes and ears) with functions (e.g., seeing and hearing). This knowledge is important, but some might view it as an endpoint for preschoolers. Our studies suggest that young children are capable of learning more, and this "more" forms a critical foundation for later science thinking skills. In a series of classroom learning experiences, children explore the unique capabilities and limits of each sense and link each sense to the kinds of information it gathers. Activities involve solving a problem, such as identifying matches or finding "which one of these things is not like the others," and each situation is set up by the teacher so that a particular sense is the best tool to solve the problem (Massey & Roth, 2004). In this way, the unique powers of each sense are highlighted.

To illustrate, one activity features a unique function of vision. Whereas shape and texture information often can be discovered through other senses, it is only through vision that we get information about color. Children are shown crayons and cube blocks on a tray, each in an array of colors. Students are presented with an opaque fabric pouch, told that the object inside matches one item on the tray, and asked to determine, without looking, whether the item is a crayon or a block. Children can succeed by feeling the item through the fabric. When asked to describe how they know that it is, for example, a crayon, children discuss attributes such as its length, skinniness, and pointy end. With the shape of the item established, we ask children to tell us its color. No amount of feeling will allow children to know for sure, although most children are happy to guess. Whereas all children agree on the item's shape, guesses about color vary considerably, which provides a potent illustration both of differing degrees of certainty when weighing evidence and of the special role of vision in determining color.

The complete activity series provides children with chances to reflect on the sources of their knowledge so that they begin to understand not just *that* they know something, but *how* they know it (Massey & Roth, 2004). Taking time to reflect on each sense and the information one can gain by using it supports metacognitive development and early awareness of knowledge (in general, and science knowledge specifically) as something that is constructed on the basis of experience. As they reflect on sources of evidence, they also are asked to explain the evidence they used to draw a conclusion, judge the adequacy of the evidence they have gathered, and determine whether more evidence is needed. Most children say that they need to see inside the pouch to know for sure what the color of the hidden item is. These developing insights are foundations for further learning about science as a way of knowing, and of coordinating and interpreting evidence (Duschl et al., 2006).

Results from the "Using Senses as Tools for Observation" unit in the PrePS program with preschoolers have been encouraging. For children in a university preschool, postunit performance on tasks that required them to determine which sense could be used to solve a discrimination problem ("Can a particular sense be used to tell which of two items is sweet, green, has a scent, etc.?") was comparable to performance in a sample of kindergarteners in urban schools (Massey & Roth, 1997). Both of the age groups represented achieved high overall scores of 84% (pre-K, university site) and 85% (kindergarten, inner city site), which encouraged us to work in schools that serve families of lower socioeconomic status.

When we pilot-tested the unit with these students, many of whom were learning both English and Spanish, we began with pretests to gauge baseline levels of understanding. The preassessments revealed that most children were unable to identify the function of many of their senses. They had difficulty completing sentences such as "With our eyes we________" and assessing the truth of statements such as "Do we taste with our ears?" A teacher in one classroom worked with us to provide a series of learning experiences about senses, and another classroom (by design) served as the comparison. After these lessons, children in the intervention classroom were more likely (79% of learners vs. 27%) to perform well when matching senses with their functions than were children who had not participated.

The results from this admittedly small sample are bolstered by recent pre- and postintervention data from a larger sample. Among a diverse (mostly dual-language learner) sample of 4-year-olds ($N = 47$, mean age at pretest = 54.3 months, range: 48–60), 15 children were able to answer more than half of the questions about the basic functions of their senses at both the pre- and posttest, which occurred approximately 3 months apart. Fourteen children could not do this at either time. Eighteen children moved from not passing to passing. No child moved in the opposite direction. As a group, children's posttest scores were reliably greater than their pretest scores, $t(46) = -7.01, p < .001$, one-tailed.

Among the 15 learners who were already further along the learning pathway than their peers (i.e., who already showed some understanding of the basic functions of their senses), we expected to find evidence of growth in their understandings of the unique capabilities of each sense. This prediction follows from the assumption that learning is more likely to occur if one already knows something about the input. The second portion of our assessment required children to apply their knowledge to a series of problem-solving situations. Children who passed the questions about the basic functions of their senses (getting eight or more correct out of 15) were introduced to a set of six unisense robots. Each robot had just one sensory capacity, marked with a familiar icon, such as an eye or an ear (Massey & Roth, 1997; see also O'Neill & Chong, 2001). Children were told about each robot's capability and then were asked a series of questions to be sure that they understand what each unisense robot can do. For example, after being introduced to the ear robot, children are asked whether it can hear (yes), whether it can see (no), and whether it can tell heaviness (no). They were asked three questions for each of the six robots (including one for muscles). Children rarely had any difficulty with these questions.

Once it had been established that children understood the robots, children completed a series of six trials. In each, the child was presented with a pair of similar items that differ on a critical dimension (e.g., two identical-looking candies with different flavors, two squares of paper of different colors). The task on each trial was to say whether a particular sense robot, all by itself, could make the discrimination between the two items (e.g., "Can the ear robot tell which one of these papers is green?"). Although overall scores were only about 68% correct at posttest, a t test comparing pre- and posttest scores showed a reliable increase in children's responding, $t(13) = -1.81, p < .05$, one-tailed.[1] We suspect that if these children had received more learning opportunities with individual feedback that the improvement would have been greater (Gelman, 1969).

Explorations of senses and observation also lend themselves to the introduction and use of certain science tools. Magnifiers work with our sense of vision to allow us to observe objects and details that are too small to see well without magnification. Balance scales can be introduced as tools that help us tell which of two things is heavier. This is especially useful when we cannot discriminate just by using our muscles, because the felt weights of the items are not

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[1] Complete data sets are available for 14 children. One child was inadvertently tested on the robots even though he achieved a score of only 7 on the pretest screener, and his data are included. Two children who passed the screener did not complete the robot tasks.

very different. Both of these science tools are often found in preschool classrooms, in the science or discovery areas; however, observations of preschool science areas confirm that children do not often visit these compared with the time they spend in the art, dramatic play, and block areas (Tu, 2006). Furthermore, when children do interact with science tools, they do not necessarily use them in the intended manner. This situation is a specific instance of a larger truth: Learners do not always interpret learning inputs or materials as intended (Gelman, 1994). Even a small amount of adult guidance can make the difference between magnifiers and balance scales being used as science tools or props to simulate cooking and stirring in dramatic play. For example, when balance scales are introduced to children as tools for observing and comparing weights of objects, children are more likely to spend time in the science area and to learn how to interpret the movement of the scale, compared with children who do not have this introduction (Nayfeld, Brenneman, & Gelman, in press).

Science journals are another tool that we incorporate into preschool science investigations. Documenting is a key feature of the well-regarded Reggio Emilia approach to early education (see http://www.reggioalliance.org/), and this evidence of the educational benefits of incorporating drawing into children's activities inspired our use of science journals with preschoolers. After children explore a new object or participate in an experiment, we ask them to record their observations in a science journal. As a science tool, journals provide a motivation for details, because these will be incorporated into a drawing and description (Brenneman & Louro, 2008). Children have a specific goal to record what they have noticed about, for example, the inside of a small cactus, seeds that have sprouted, or balls rolling down ramps of different heights. Adults can support children's attention to key features, and enhance the representational power of their journal entries, by constraining the task in certain ways. Focused observation prompts from adults can be useful for encouraging more realistic recordings of information (Vlach & Carver, 2008). Incorporating contrast also encourages young children to draw more realistically (e.g., Davis & Bentley, 1984). For example, when we ask children to represent the results of a growth experiment by drawing both a healthy plant and an unhealthy plant, drawings are more likely to include relevant features, such as color, stem shape (droopy or straight), leaf size, and number of leaves, because these contrasts are relevant to plants' health (Brenneman & Louro, 2008).

The use of science journals can help children solidify their understandings because they provide a chance for learners to think again about a science experience as they record what they see and know. Deeper, more durable learning occurs when hands-on learning experiences are enhanced with opportunities to apply new knowledge to a related problem, to make a graph, or to create a journal entry (see also Massey, 2004). Journal entries also provide teachers with insight into students' observations and understandings. The drawings that children create provide a window into their ideas about the most important or relevant features of an object or situation (Doris, 1991; White & Gunstone, 1992). Although their drawing skill can limit the features children can represent clearly, our habit of asking them what they would like to write on their drawing provides an opportunity for them to describe their observations and drawings (Brenneman & Louro, 2008; Gelman et al., 2009). As teachers listen and probe, they have the opportunity to assess what children have learned from their science explorations and to determine what might have been misunderstood.

Conclusions and Future Directions

We have found that young children's inquisitiveness fits well with a program that teaches them to make systematic observations about questions of interest, using the tools and practices of science. Through encouragement in the use of these tools, processes, and their technical names across a variety of content lessons, children acquire science terms as they practice using the skills and tools to which those terms refer. It is clearly possible to encourage young scientists-in-waiting to start to become scientists. As an illustration, consider the nature of the conversation we had recently when we returned to a classroom we had been in a month earlier. At that time, we had engaged children in discussions and experiments about the function of blubber for animals that live in cold environments (Gelman et al., 2009). Many children approached us to ask whether we remembered the blubber. We responded by asking questions about what the children themselves remembered about the experimental procedure, about the question we were exploring, and about the results that we had found. Children did a remarkable job, using vocabulary words such as *blubber, test,* and *experiment.* They were able to describe the method (use one bag filled with blubber/vegetable shortening and one that is not and place them into snow) and the results (we found out that blubber keeps our hands warmer). When asked how she knew the answer to a particular question, one girl responded, in a matter-of-fact tone, "I'm a scientist," a phrase we had not used with her.

This example illustrates that the children remembered the key vocabulary, goals, and conditions of the experiment. The conversation was also extremely animated and full of positive affect. This is quite typical of most of the children this age with whom we have worked. They pay attention, listen, and participate in lessons that occur during group time—even if these go on for 20 minutes. Many children and/or their parents tell us that the school activities led to at-home discussions about what the children had done during the school day, taking science out of the classroom and into the rest of their lives (Gelman & Brenneman, 2004). The inclusion of opportunities to do classroom science builds on children's natural proclivities, extends these to incorporate the practices and tools of science, and—we hope—helps ensure that science continues to be an enjoyable and positive experience that is considered an integral part of everyday experience. By providing repeated opportunities to engage productively with both the content and processes of science, educators foster the promise in each young scientist-in-waiting, providing critical support as he or she grows from child to scientist.

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