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From Everyday to Scientific Observation: How Children Learn to Observe the Biologist's World

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This article explores the development of observation in scientific and everyday contexts. Fundamental to all scientific activity, expert observation is a complex practice that requires the coordination of disciplinary knowledge, theory, and habits of attention. On the surface, observation appears to be a simple skill. Consequently, children may be directed to observe, compare, and describe phenomena without adequate disciplinary context or support, and so fail to gain deeper scientific understanding. Drawing upon a review of science education, developmental psychology, and the science studies literatures, this article examines what it means to observe within a disciplinary framework. In addition, everyday observers are characterized and a framework is proposed that hypothesizes how everyday observers could develop practices that are more like scientific observers.

Keywords: scientific observation, science-as-practice, everyday observation, science education.

> "You see, but you do not observe."
> Sherlock Holmes, *A Scandal in Bohemia*

Scientists make observations to learn about the world. Observation is fundamental to all scientific activity and to all scientific disciplines (Daston & Vidal, n.d.; Norris, 1984): It is the foundation on which hypotheses and data are based, the lens by which hypotheses are strengthened or refuted (Mayr, 1997; Moore, 1993), and often the stimulus for scientific discovery (Klahr & Simon, 1999; Mayr, 1997; Simon, 2001). Reliable data—whether collected in the field or laboratory—depend upon skilled observation to ensure the collection and accurate documentation of critical evidence and to build explanations and theories.

On the surface, scientific observation is deceptively simple: Phenomena happen, phenomena are observed, and phenomena are recorded. How difficult can it be to observe scientifically? After all, children everywhere make observations in order to learn about their everyday world (Rogoff, Paradise, Mejia Arauz, Correa-Chavez,

& Angelill, 2003). But, as Sherlock Holmes astutely remarked, seeing is not observing.

To observe scientifically requires much more than sensory perception and using one's senses. Sensing—although highly tangible—is only one aspect of observation. True scientific observation requires coordination of disciplinary knowledge, theory, practice, and habits of attention (Daston & Vidal, n.d.). To illustrate what we mean, we turn to lessons learned from the early development of Cornell Ornithology Lab's Classroom FeederWatch curriculum (Trumbull, Bonney, & Grudens-Schuck, 2005). In this program, middle school students were expected to observe living birds as a means of engaging in authentic scientific inquiry. The premise seemed simple: Strategically locate birdfeeders around school grounds, systematically observe living birds, engage in authentic inquiry, and learn about the biology of birds. Yet, evaluation of the curriculum revealed no change in students' disciplinary knowledge or in their understanding of inquiry skills. Moreover, most students failed to see how their observations might help ornithologists. What went wrong?

Evaluation suggested that the developers—who included educators and expert ornithologists—had underestimated the complexity of observational practice, its interrelationship with disciplinary knowledge, and the degree to which teachers and students needed scaffolding to support systematic observation. Like so many, they had assumed it is easy to observe birds. Yet, problems with identifying and counting birds soon emerged: Students could not identify birds in flight, nor could they distinguish between individual birds, making it impossible to generate accurate population counts. As trained observers, ornithologists know what features to observe when identifying kinds of birds and to look for field marks to identify individual birds in flight. Lacking this specialized knowledge and practice, students were unable to make scientifically meaningful observations.

Attracting sufficient numbers and kinds of birds is essential to systematic observation of birds, but to everyone's surprise, birds did not flock to the classroom feeders. The team had underestimated how their knowledge of ecology informs the identification of environmental conditions that attract birds and, as a result, provided too little guidance for placing the feeders. Without this knowledge, teachers and students may have placed the feeders where it was convenient to observe the feeders without also considering the ecological conditions necessary to attract birds. Trumbull et al. (2005) concluded that "[to] learn a sophisticated form of observation particular to a discipline . . . careful observation is structured by knowledge about birds and by knowing the kinds of questions to ask about the birds one may see" (p. 13). This was easy for the scientists—they had amply rehearsed these activities—but unfamiliar territory for students and teachers.

This example illustrates several concepts important to the development of scientific observation. First, systematic observation is a challenging enterprise, yet one that is often underestimated by educators and researchers (Chinn & Malhotra, 2002a; Metz, 2000; Norris, 1985; Smith & Reiser, 2005). Too often, observation is cast as a general everyday skill that requires little more than noticing and describing surface features (Ault, 1998; Chinn & Malhotra, 2001; Metz, 1995). Consequently, students look at phenomena without developing new knowledge or associating their observations with scientific reasoning and explanations (D. Ford, 2005). The student observations in this example were more characteristic of everyday observation.

This leads to the second point: Scientific observation is not a domain-general practice, but one that goes hand in hand with disciplinary knowledge, theory, and practice (Ault, 1998; Daston & Vidal, n.d.; D. Ford, 2005; Finley & Pocovi, 2000; Mayr, 1982; Norris, 1984). When observations are disconnected from disciplinary contexts, we see but we do not observe. Without sufficient understanding of the underlying theoretical concepts of ornithology, and without awareness that ornithologists have sophisticated observational habits, students failed to learn about the biology of birds and authentic scientific inquiry.

Third, learning to observe scientifically necessitates bootstrapping between specific disciplinary knowledge, theory, and practice (D. Ford, 2005; Lehrer & Schauble, 2004; Metz, 2000, 2004; Norris, 1985). Although children are intent observers whose everyday observations help them to understand and negotiate the world (Rogoff, 2003), and their observations may share similarities with scientific observers (Carey, 1985; Gopnik, Meltzoff, & Kuhl, 1999; Vosniadou & Brewer, 1994), children still need support to be scientific observers. Perhaps with more knowledge of bird ecology, the feeders might have been located in places that would have attracted more birds as well as meeting the students' observational requirements.

Finally, this example illustrates some fundamental differences between expert and novice observers. Expert ornithologists appeared to effortlessly detect field marks to distinguish individual birds, whereas students had difficulty even identifying kinds of birds. This perceptual acuity is evident in other experts, such as chess masters who can perceive meaningful patterns and accurately reproduce the locations of chess pieces on a game board from memory (Chase & Simon, 1973; Chi, 1978). Like other experts, the ornithologists have hierarchical, highly organized structures (within their discipline) that enable them to effectively encode and organize the world differently from novices and to efficiently notice and recall meaningful patterns (Ericsson, 1996; Hecht & Proffitt, 1995; Patel, Kaufman, & Magder, 1996).

The purpose for this article is to understand what it means to observe scientifically. Specifically, we examine what distinguishes everyday observers from scientific observers and to consider the kinds of activities that support observations that are increasingly scientific. To do so, we pursue three major strands of inquiry: (a) What does it mean to observe within a disciplinary framework? (b) What do children's everyday observations look like? and (c) What knowledge, tools, and practices do children need in order to observe within a disciplinary framework? We do this by bringing together several literatures: developmental psychology, science education, and science studies. Although we include examples within school contexts, our primary interest is the out-of-school informal and everyday contexts where children encounter biological phenomena.

Observing Like Expert Biologists

> In a profession more observational and comparative than experimental, the ordering of diverse objects into sensible categories becomes the sine qua non of causal interpretation. A taxonomy is not a mindless allocation of objective entities into self-evident pigeon-holes, but a theory of causal ordering. Proper taxonomy requires two separate insights: the identification and segregation of the basic phenomenon itself, and the division of its diverse manifestations into subcategories that reflect process and cause. (Gould, 1986, p. 63)

What does scientific observation look like when practiced by expert biologists? We suspect that many readers may think of observation solely in terms of controlled experimentation in which scientists observe the results of manipulated variables. But biologists also use many nonexperimental methodologies to observe and understand phenomena. Our focus here is on observational biologists who primarily use the comparative method and who systematically contrast the features of organisms and classify variations among organisms (Futuyma, 2001; Mayr, 1982). Although such observations are sometimes misconstrued as being merely descriptive, when biologists observe the morphological features of organisms, they are simultaneously inferring evolutionary relationships and testing hypotheses about the causal order of organisms (Futuyma, 2001; Gould, 1986, 2002; Mayr, 1982).

Our interest in the practices of observational biology is twofold. Systematic observation and comparison is a complex method used by biologists, yet one that is often misunderstood and treated as a simple skill by educators and others. Consequently, children may be directed to observe, compare, and describe phenomena without meaningful disciplinary context and without gaining deeper scientific understanding. Second, observational biologists typically engage scientifically at the level of organisms, which are tremendously fascinating to children and which children can easily access and observe during the course of their daily activities.

Expert Noticing and Reasoning

It would be impossible to navigate an enormously complex and diverse nature without some interrelated system of observation. It would be similarly impossible to make scientifically meaningful observations and comparisons without taxonomy (Mayr, 1982). Biological taxonomies are comprised of highly detailed morphological descriptions of organisms and hypothetical arrangements of groups of organisms. The underlying principle for these groupings is that members of taxon (i.e., a distinct group of organisms) share a common descent and have more characteristics in common than those that do not (Futuyma, 2001; Mayr, 1982, 1997). For this reason, biologists arrange organisms into hierarchical levels of increasingly broader categories—species to genus to family and so on—as a means of interpreting evolutionary process and cause.

Based upon a study of expert systematic botanists, Alberdi, Sleeman, and Korpi (2000) concluded that taxonomies enable scientists to look beyond the surface morphological features of organisms to extract information and to infer relationships that are not readily apparent. For instance, upon first seeing an individual plant, close observation of its many parts roused prior knowledge about the plant's life cycle, habitat, geographical nativity, and taxonomic family.

The study also suggested that the ways botanists systematically compare plants depend upon the extent to which morphological features correspond to taxonomic expectations. When observing two or more plants that conformed to taxonomic expectations, botanists activated a systematic comparison in which information from one plant triggered a point-by-point comparison of another plant (e.g., pistil to pistil). In this way, botanists identified similarities and differences between plants, frequently comparing similarities between negative and positive instances (i.e., "It's not like that, it's like that . . . ") or comparing differences between negative instances (i.e., "It's not like that, nor like that . . . ").

In contrast, when faced with unexpected observations, botanists compared a botanical feature of one plant (e.g., pistil) with the categorical features (e.g., floral structures) of another:

> "This is in the category? This really does puzzle me . . . because . . . it's got the branched flower stem, but totally different flower head . . . unless it's something to do with the fruits. . . . It's nothing to do with pollination, really . . . they're not all wind dispersed. (Alberdi et al., 2000, p. 74)

By shifting attention to the whole floral structure—the primary feature for grouping plant families—botanists were able to make theoretically driven comparisons and to speculate about alternative taxonomic groupings. In effect, to resolve moments of uncertainty, botanists looked beyond the morphological aspects of individual flowers and inferred evolutionary relationships based upon a hypothetical organization of organisms.

This study illustrates several points about the nature of expert scientific observation. First, perception is foundational to learning across the continuum of knowledge acquisition (Jones & Smith, 1993; Mervis, Johnson, & Scott, 1993). Expert botanical observers are extremely adept at coordinating their perceptions of phenomena (e.g., floral structure) with abstract, theoretical entities (e.g., plant families). This seamless coordination is also evident in how biologists in other contexts use existing knowledge to notice and organize key features that support inferences about deep principles and relationships within biological systems (Hmelo-Silver & Pfeffer, 2004; Medin, Lynch, Coley, & Atran, 1997).

Second, systematic observation and comparison can be a powerful method for supporting complex hypothesis testing without experimental manipulation (Mayr, 1982). In this study, botanists implicitly used taxonomic theory to select diagnostic features (e.g., pistil, stamen) that supported point-by-point comparisons. In this way, taxonomies—like other theories—draw the observer's attention to theoretically meaningful features (Ault, 1998; Gould, 1986). When surprised by anomalous observations however, botanists explicitly referred to theoretical expectations (i.e., "This is in the category?") and indirectly tested taxonomic expectations by comparing plants at higher levels of categorization. Taken together, these points reveal how perception and observation are integral to scientific practice.

Asking the Right Questions

The Alberdi et al. (2000) study also reveals that asking the right questions at the right time is a powerful heuristic. Doing so enables biologists to bring order to a vast and complex nature by drawing attention to specific aspects of organisms and biological environments that have disciplinary meaning. Doing so also ensures that data are collected and analyzed to answer questions and solve problems (Moore, 1993).

Mayr (1997) asserted that three fundamental questions drive biological observations: What? How? and Why? Accordingly, what-questions are the foundation of any scientific discipline and are key to establishing the facts of science and "fueling speculation" (Haila, 1992, p. 247). The resulting catalogue of biological descriptions is fundamental to the comparative activities of observational biologists (Mayr, 1997). Recall that botanists initiated their observations by noticing a plant's features and activating prior biological knowledge, which in turn supported theoretically driven comparisons (Alberdi et al., 2000). What-questions also filter complex environments and focus a biologist's attention as data are collected in the field. For expert biologists, generating many what-questions during data collection is a productive strategy for extracting information from observed phenomena. As it is, biologists with more expertise tend to ask many more what-questions than less experienced biologists, who generate many hypotheses but few questions (Larreamendy-Joerns, Sandino, & Tascon, in press). Similar to everyday observers, less experienced biologists may generate explanations before collecting all of the available data.

Both how- and why-questions are necessary to questions of biological causation that occur within the time scale of the observational activity as well as the evolutionary history of the organisms (Gould, 1986, 2002; Haila, 1992). Whereas how-questions focus on current conditions and concern immediate causations (e.g., How does an organism function?), why-questions focus on the evolutionary factors that account for all aspects of living organisms over time and concern ultimate causation (e.g., Why are some organisms comparatively similar and others so dissimilar?).

Each type of question is critical to Gould's (1986) argument that proper taxonomy requires that the phenomenon must be identified and segregated and that taxonomic ordering must reflect process and cause. Two of these questions are evident in the Alberdi et al. (2000) study. For example, when botanists initiated observations by noticing a plant's features, they essentially sought to answer the question, "What is this?" It is also possible to infer that when plants did not meet taxonomic expectations, botanists activated a why-question as they made comparisons and searched for characteristics of common ancestry. Had the botanists been concerned about the distribution of these species, they may have generated questions about how floral structure affects seed dispersal. In this way, each type of question responds to the problem at hand and draws attention to critical aspects of the phenomenon.

Documenting Observations

The questions that biologists ask guide their observations and ultimately the data they record and collect. Many of these records are eventually transformed into inscriptions—written representations of phenomena—that allow scientists to ask different questions of phenomena and to consider alternative interpretations of data (Latour & Woolgar, 1986). These may assume relatively identifiable forms (e.g., line drawings, models) as well as more abstract forms (e.g., diagrams, graphs, taxonomic trees, written descriptions). Whatever their form, inscriptions both reduce and enhance information in order to highlight theoretically important features and relations, such as the field marks of birds or the distribution of populations that are not easily discerned when phenomena are observed in complex settings (Haila, 1992; Lynch, 1990; Myers, 1990). In this way, inscriptions serve two primary purposes: to document phenomena (Janovy, 2004) and to support scientific argumentation (Latour, 1990; Lynch & Woolgar, 1990).

Inscriptions reveal what some have described as the inseparable bond between scientific observation and scientific theory (Feyerabend, 1965; Hanson, 1958; Popper, 1972; T. S. Kuhn, 1962). It is not surprising that inscriptions necessarily reflect the theories, questions, and practices of each scientific discipline (Daston & Vidal, n.d.; Kitcher, 1984; Metz, 1995). Consider that the stylized written descriptions used to support botanists who study relationships among kinds of plants would be of limited use to ecologists concerned with the distribution of common species. Over time, inscriptions are refined and standardized, which is essential to the collective scientific enterprise but also to the comparative work of observational biologists. Imagine how challenging it would be to test and revise taxonomic hypotheses without strict disciplinary practices of representation.

Latour (1990) argued that inscriptions ultimately benefit scientific argumentation because they can be reduced to elegant geometrical equations. However, observational biologists interested in the emerging characteristics of organisms at different levels of natural systems may argue that there are points beyond which phenomena cannot be meaningfully reduced (Dobzhansky, 1966; Gould, 2002; Kitcher, 1984; Mayr, 1997). It seems worth noting that biologists also document their observations by collecting the stuff of nature: fossils, preserved specimen, and living collections. Similar to inscriptions, the purpose of these collections is to preserve change and to support scientific documentation and argumentation. Biological collections can serve these purposes because they include theoretically important specimen, which are representative of populations rather than attempts to include all of nature. The specimen in these collections are often reduced and enhanced in order to highlight critical features. For example, the pressed plant specimen in herbaria include only those features, such as floral structures, which support disciplinary knowledge and comparative reasoning. According to Latour, a collection's primary disadvantage is that it cannot be easily manipulated. However, certain biologists might count this fact among their principle advantages.

Productive Dispositions

Until now we have considered how the demands of the biological discipline affect observation. Here we consider how the interests and identity of individual biologists may also drive observations. For those biologists who are also self-described naturalists, the quest for knowing more about biology is often in response to a profound fascination with particular organisms (Futuyma, 1998; Gould, 2002; Greene, 2005; Janovy, 2004; Wilson, 1995). Dobzhansky, for example, was known to rearrange plans and travel far distances for the chance of seeing new species of fruit flies (Ayala, 1985). Whether described in terms of love, admiration, or raison d'être, the desire to understand particular organisms appears to be a motivating influence for sustained interest. Consider, for example, Gould's (2002) perceptive estimation of the habits of practicing scientists: "[There is] hardly a natural historian, dead or alive, that has ever failed to locate his chief delight in the lovely puzzles, the enchanting beauty, and the excruciating complexity and intractability of actual organisms in real places" (p. 1338).

Gould's (2002) insight alludes to the role that real organisms in real places may play in the development of a biologist's interests and identity. For some, the sense of being a biologist can only be fully realized in the field (Janovy, 2004). But is it just raw nature at work here? Evidence suggests that informal interactions among biologists, in and out of the field, significantly contribute to forming and sustaining habits of attention (Bowen & Roth, 2007; Kohler, 2002; Larreamendy-Joerns & Sandino, 2004). Wherever these biologists gather, informal conversations soon focus on the observation of organisms: They talk—often in extensive detail—about the organisms they are looking at now, the organisms sought but not found, and their plans for future looking. It should be no surprise that such deeply embedded observational habits—cultivated across settings and during years of profound curiosity—spill into a biologist's everyday activities (Janovy, 2004). This habit of observing cannot be simply switched on and off, so that everyday experiences like walking in a park or across a city become new opportunities for further looking and observation of the biological complexity all around.

To summarize, unpacking scientific observation allows us to understand that observational systems use specific practices and tools to address specific questions and problems (Haila, 1992). These systems are made up of components that are necessarily interrelated: The nature of the phenomena and the disciplinary framework inform the biologist's questions, which in turn, affect how data are collected, represented, and brought to bear in scientific argumentation. In addition, habits of practice may interact with a biologist's identity and observation of the everyday natural world. The components making up any observational system necessarily reflect specific disciplinary problems, questions, and habits, so that the actual dimensions of each component may be different from those highlighted here. Nevertheless, the practice of scientific observation necessarily includes noticing, theoretical expectations, observational records, and productive dispositions.

Children's Everyday Observations

Having explored what it means to observe like an expert biologist, we now consider what it means for children to observe like everyday observers. Some have argued that positioning everyday in contrast to scientific is potentially pejorative and negates the generative nature of everyday cognition, which is an entity in its own right (Lave, 1988; Warren, Ogonowski, & Pothier, 2005). More typically however, everyday has been positioned as being qualitatively different from scientific, whether it is knowledge (Driver, 1994; Gopnik, 1996), explanation (Brewer, Chinn, & Samarpungavan, 2000; Keil & Wilson, 2000), argumentation (Bell, Bricker, Lee, Reeve, & Zimmerman, 2006; Smith & Reiser, 2005), or observation (Daston & Vidal, n.d.; Park & Kim, 1998; Vosniadou & Brewer, 1994). From this perspective, everyday observations are practical and possibly intuitive experiences that both derive from and inform daily life—understanding that "sweaters keep us warm even though a sweater sitting on a table is not warmer than the surrounding room" (Chinn & Malhotra, 2002a, p. 339) or awareness that some objects sink and others float (Penner & Klahr, 1996). Adhering to a scientific concept of everyday observation, we might adopt Mayr's (1997) use of simple observation to identify those that are largely descriptive and noncausal in nature. For the purpose of this article, we define everyday observations as those that occur with little or no knowledge of the constraints and practices of scientific disciplines. This distinction is not intended to diminish observations that occur in everyday contexts, for everyday observation can be a powerful mechanism for learning.

In fact, children everywhere make observations in order to learn about their everyday world (Goncu & Rogoff, 1998; Rogoff, 2003; Rogoff et al., 2003; Scribner & Cole, 1973). From children's earliest development, active observation and emulation of others—with little or no explanation—are key to learning cultural norms and practices, including early language development, human behavior, and the manipulation of tools and objects (Falk & Dierking, 2000; Gopnik et al., 1999; Rogoff et al., 2003; Tomasello, 1999).

Although children everywhere engage in observation, cross-cultural research reveals that observation is influenced by and practiced within cultural contexts. For some children, observation, in concert with participation in shared endeavors, is the primary means for learning the skills, values, and mannerisms of their culture (Philips, 1972; Rogoff, 2003). Rogoff (2003) noted that in cultures where children participate in community activities, they are expected to be simultaneously alert to many things and to learn activities through "keen observation" and emulation. In comparison, in cultures where observation is not the primary source of learning, such as that of U.S. middle-class families, children are encouraged to observe one thing at a time and to rely on explanations more than observation to learn everyday activities. For example, U.S. parents routinely assume responsibility for explaining their children's observations during shared activity in everyday settings (Ash, 2003; Callanan & Oakes, 1992; Crowley et al., 2001).

Although considered powerful in everyday cultural contexts, when considered within scientific contexts, children's observational skills are portrayed as unsystematic, unfocused, and unsustained (e.g., Chen & Klahr, 1999; D. Kuhn, 1989; D. Kuhn, Amsel, & O'Loughlin, 1988; D. Kuhn, Garica-Mila, & Anderson, 1995; Keys, 1999; Klahr, 2000; Roth, Campbell, Lucas, & Boutonne, 1997; Schauble, 1990, 1996). In such contexts, children might be described as classic "dust-bowl empiricists" who make lots of observations but have trouble encoding evidence, making valid inferences, and connecting observation to theory. Accordingly, children's everyday observations have been shown to do little work toward building complex scientific understanding of natural phenomena (D. Ford, 2005).[1]

To better understand what kind of everyday observers children are in scientific contexts, we examined the scientific reasoning and science education literatures in which observation was either the focus of the research or at least played a key role in the research task. The following is organized across three of the dimensions identified as components of expert scientific observation: noticing, expectations, and observational records. The fourth component, productive dispositions, will be explored in the next section.

What Children Notice

Perception is a fundamental aspect of scientific observation, whether the observer is an expert or novice. Whereas scientists notice multiple dimensions of phenomena—meaning microscopic and telescopic, novel and familiar, surface and abstract—children typically notice "middle-sized, close, perceptible, and familiar objects" (Gopnik, 1996, p. 492). We see evidence of this in observation tracking tasks in which infants notice and imitate facial expressions or attend longer to anticipated behaviors of nearby people and objects (Gopnik et al., 1999; Meltzoff, 1988, 2005). This pattern of perception is also consistent with findings from environmental psychology and cultural geography in which young children are more apt to notice separate objects in familiar landscapes—a tree stump, bubbling water in a section of a stream—rather than complex systems or distant landscapes (Hart, 1979; Tuan, 1974).

Even as children mature, they tend to notice phenomenological features and events narrowly and do not spontaneously notice aggregates such as populations, distributions, hierarchical orders, or complex systems. Consider that seventh graders typically mentioned only one morphological feature when comparing differences between two fish (Hmelo-Silver & Pfeffer, 2004), or that fifth graders spontaneously focused on individual plants rather than populations when tracking plant growth (Lehrer & Schauble, 2004), or that sixth graders had difficulty connecting their observation of termite behavior occurring at the micro level with events at the macro level (Penner, 2001). These examples are not exceptional: The scientific reasoning and education literatures provide ample evidence that children are more likely to notice isolated instances of evidence than they are to consider all of the available evidence, prompting Klahr (2000) to conclude that what children consider to be sufficient evidence to support a hypothesis is frequently inadequate. Similarly, in studies using an experimental model, children typically consider only a portion of the possible variables to manipulate (Klahr, Fay, & Dunbar, 1993; Penner & Klahr, 1996; Schauble, 1990) or the possible experimental results to observe (Karmiloff-Smith & Inhelder, 1975; Schauble, 1990). For instance, children often notice final experimental results without attending to causal interactions that occur along the way (Schauble, Glaser, Raghavan, & Reiner, 1991; Smith & Reiser, 2005; White, 1993). These examples represent just the tip of a much larger iceberg: Across settings and ages children seem predisposed to arbitrarily noticing phenomena.

Why do they do this? Some might argue that young children are concrete thinkers who focus on the salient features of phenomena because they cannot reason about abstract, underlying causal connections (Flavell, 1985; Tversky, 1985). If this were true we might expect that with increasing age, a child's attention would be more evenly distributed between noticing surface features and recognizing underlying relationships. Evidence suggests otherwise. Consider, for example, that children's explanations typically stress observable biological processes such as behavior and growth with little mention of underlying causal principles, whether the children are in elementary, middle, or high school (Abrams, Southerland, & Cummins, 2001). Likewise, both novice middle school students and novice teachers focused on an aquarium's structural elements (e.g., sand, fish, plants) but failed to recognize how these components also simultaneously functioned as parts of a complex and dynamic system (Hmelo-Silver, Marathe, & Liu, 2007; Hmelo-Silver & Pfeffer, 2004). Thus, difference in age alone is insufficient to account for this observational pattern.

A more satisfactory explanation is that children tend to focus on the surface features of phenomena because they lack domain knowledge (Chi, Hutchinson, & Robin, 1989; Johnson & Mervis, 1994, 1997) and because many phenomena are too complex to explain without discipline-specific knowledge (Driver, 1983; Wood-Robinson, 1995). The degree to which children notice surface or deep features is related to the extent of their associated knowledge. For example, Johnson and Mervis (1994) found that 5-year-olds with little knowledge of shorebirds compared different birds by referring exclusively to morphological features such as size, color, and shape. As their knowledge about shorebirds developed, so did their ability to notice and coordinate multiple physical and behavioral attributes into patterns that supported grouping shorebirds around abstract concepts of form and function and natural order. In particular, more knowledgeable 5-year-olds developed the ability to notice and compare multiple occurrences of features such as bill and toe structures, which in turn supported inferences about functional behavior and categorical relationships among shorebirds that distinguish them from other kinds of birds.

So what can everyday observers learn from simple observation in the absence of prior knowledge? A study in which 12-year-old novices conducted self-directed observations of brine shrimp suggests that although this activity may stimulate children's curiosity and interest, the potential for learning is limited (Tomkins &

Tunnicliffe, 2001). As might be expected, children primarily noticed the most salient features and behaviors of the shrimp. They generated lists of features, such as noticing differences in color and shape, but missed opportunities to make connections, such as failing to associate color and shape with differences in the sex of the shrimp. Their observations also reinforced misconceptions (i.e., students misinterpreted mating behavior for child-rearing practice) and a tendency to infer meaning from only a portion of the evidence. When children have little or no knowledge of biological phenomena, they are reduced to compiling lists of isolated instances. Such lists are poor measures of learning, particularly as children indiscriminately include both relevant and irrelevant features (D. Ford, 2005; Driver, 1983; Keys, 1999). When children are cast into an activity with inadequate knowledge and instructional support, observation becomes a weak method for collecting data rather than a powerful method for reasoning scientifically.

In short, everyday observers fail to notice the right things. Instead, they notice many irrelevant features and behaviors that fail to forge connections or to support deeper understanding of complex phenomena. Disciplinary knowledge, however, can filter, focus, and foster understanding.

Expectations and Observational Evidence

It should come as no surprise that children's everyday expectations are closely associated with what they notice. Children's everyday expectations arise from their empirical observations of everyday life (Vosniadou & Brewer, 1992, 1994), often coinciding with periods of intense observation and experimentation (Driver, 1983; Gopnik, 1996). Through repeated exposure, children begin to expect objects and phenomena to behave in ways that conform to their direct observations. For example, a child plays with rubber ducks and soap in the bathtub and comes to expect that heavier objects will sink and lighter objects will float. Although observations like these are experimental in nature, children also form expectations about phenomena they cannot manipulate. For example, night after night a child looks at the sky and comes to expect to see the moon and stars when night falls. And although it may be true that perception plays a proportionally larger role for younger children (Gopnik, 1996), observation of phenomena and the inferences drawn from observation continue to play a critical role in the development of children's everyday expectations, even as other sources are incorporated (Duschl, Schweingruber, & Shouse, 2007).

The relationship between observation and expectations is not unidirectional, however. Children's expectations also influence what they do and do not notice. Expecting to see the moon only in the night sky, children often fail to see the moon in the morning sky (Vosniadou & Brewer, 1994). So it would seem that children see the world through their own "conceptual spectacles" (Driver, 1983, p. 5). This tendency of seeing what one expects to see, which Klayman and Ha (1987) referred to as confirmation bias, suggests that children actively seek evidence that supports their expectations and ignore evidence that is contradictory. This tendency is apparent in a classic study in which Karmiloff-Smith and Inhelder (1975) asked young children to balance blocks, some of which could be balanced on geometric center and some of which had hidden weights and could not be balanced on geometric center. Expecting that "things balance in the middle," children tried balancing each block at its geometric center, even though multiple attempts failed. Furthermore, they ignored observations made during an earlier exploration of the blocks' properties in which they had successfully balanced the blocks. Why could they balance the same blocks in one instance but not in another? It is possible that when children had only weak expectations about the blocks' properties they could explore the blocks, observe their behavior, and balance the blocks. However, once children formed the expectation that "things balance in the middle," they excluded contradictory observational evidence from consideration and persisted in attempting to balance all blocks at their geometric center.

In addition to affecting what they notice, everyday expectations also influence how children initially structure a problem and decide which features may be important to observe (Schauble et al., 1991). This is evident in a study in which 10-, 12-, and 14-year-olds designed experiments to explore the properties associated with the rates at which objects sink (Penner & Klahr, 1996). Expecting that heavier objects sink faster than lighter objects, 78% of all participants started by comparing objects in which one was heavier than the other, although objects of different shapes, sizes, and materials were also available.

These examples make clear that everyday expectations may or may not conform to scientific explanations. A child might rightly expect to observe the moon in the night sky but mistakenly believe this is due to clouds blocking the sun (Vosniadou & Brewer, 1994). Regardless of scientific accuracy, expectations can be quite persistent and pose a significant challenge to whether or not children successfully coordinate what they see with what they expect.

The ability to critically evaluate evidence in light of one's expectations is considered to be the hallmark of scientific reasoning (Feyerabend, 1965; Finley, 1982; Norris, 1984) and to be evidence of conceptual change (D. Kuhn, 1989; D. Kuhn et al., 1988). There is general agreement that young children can distinguish hypotheses from evidence and can make judgments about evidence. Children are greatly aided in these endeavors by prior knowledge, or in the absence of prior knowledge, when the hypotheses are plausible (Fay & Klahr, 1996), the variables are few (Sodian, Zaitchik, & Carey, 1991), and the phenomena provide clear feedback (Klahr et al., 1993).

Of course, everyday environments rarely, if ever, include few variables or provide clear feedback: Everyday environments are complex, populated with vast, diverse, and dynamic phenomena. Without sufficient knowledge or experience, it is extremely difficult for everyday observers to meaningfully decipher such overwhelming complexity, whether looking at the morphological features of fish in a school lab, birds in flight, or the moon in the night sky. This inability to decompose complexity into smaller and smaller parts may make it more likely that everyday observers will impose personal beliefs and expectations onto the phenomena. What is more, it may be more difficult for children to evaluate their observations or to modify robust expectations in contexts similar to those in which their expectations were formed initially (Penner & Klahr, 1996; Sodian et al., 1991).

Thus, the combination of complex phenomena, robust expectations, and the tendency to seek confirmatory evidence complicates the ability of children to critically evaluate observational evidence. Furthermore, prior expectations assume greater influence on what individuals see when sensory stimuli are difficult to decipher (Brewer & Lambert, 1993). This dynamic relationship is evident in the Penner and Klahr (1996) study in which observations and the interpretation of observations were influenced by the firm belief that weight causes objects to sink at faster rates. Recall that participants designed most of the experiments to compare the sink rates of heavier and lighter objects. Ironically, many comparisons were between objects with negligible differences in weight (e.g., 0.9, 0.5 grams) or sinking times (e.g., 0.8, 0.6 seconds). The resulting similarities in weight and appearance would challenge any observer to detect such subtle differences. Yet, many participants reported observing heavier objects to "sink a little faster" and attributed faster sinking times to small differences in weight, a tendency that was more frequent among 10-year-olds (72%) and significantly less so among 14-year-olds (20%).

So it would appear that when phenomena are difficult to observe, children simply default to what they expect to see. However, this is not necessarily the case, especially when children have expectations with varying degrees of robustness. Consider a study in which fourth graders observed two rocks of similar size that were dropped simultaneously to the ground (Chinn & Malhotra, 2002a). Given the inherent weakness of the stimuli, it seems likely that all children would favor seeing what they expected to see. And in fact, 72% of students who made the scientifically accurate prediction that the rocks would reach the ground simultaneously reported observations that matched their predictions. However, students who predicted that the rocks would reach the ground at different times were more likely to record an observation that differed from their prediction. Why the difference? The researchers hypothesized that students who made the scientifically accurate prediction had schemas that enabled them to "detect faint signals" of an existing pattern. If true, this might also suggest an alternative explanation: One group's beliefs were more entrenched than the other. Once a belief becomes entrenched, it is increasingly difficult to respond to surprising observations and to modify one's expectations (Chinn & Brewer, 1992, 1998). In scenarios where phenomena are so similar in appearance, we would expect students with strong beliefs to make observations that match their predictions. On the other hand, students with less entrenched beliefs might be expected to observe a range of possible results, including those that differ from their predictions.

The ways in which the children in these studies respond to surprising observations is far from remarkable. The tendency to seek evidence that supports one's expectations or to ignore, distort, or selectively observe evidence that contradicts preferred expectations is common, even among adults (Chinn & Brewer, 1992, 1998; D. Kuhn et al., 1988; Klayman & Ha, 1987). Nevertheless, observation plays a central and active role in how children and adults evaluate evidence (Brewer & Lambert, 1993; Driver, 1983) and can both impede and support conceptual change (Chinn & Malhotra, 2002a).

Using Observational Records

It is common knowledge that children spontaneously make drawings. Even when paper and pencil are unavailable, children find everyday materials such as sticks and dirt to sketch the world around them (Hart, 1979). In contrast, there is little or no evidence to suggest that children spontaneously record their observations of biological phenomena in out-of-school contexts. Even biologist E. O. Wilson, who spent countless childhood hours observing biological objects exhibited in natural history museums, did not chronicle his observations until later in adolescence (Wilson, 1995). It should not be surprising that children express little enthusiasm for recording their observations even when they are enthusiastic about making observations (D. Ford, 2005).

In fact, the science education and developmental literatures are rife with examples in which children make observations without productively generating or using records. Many times, children either relinquish responsibility for recording data to others (Gleason & Schauble, 2000; Haslam & Gunstone, 1998) or fail to record observational evidence altogether (Garcia-Mila & Andersen, 2007; Schauble, 1990). For instance, during a shared experimental activity, 9- to 12-year-old children recorded a mere 5% of the data whereas parents recorded 77% of the data (Gleason & Schauble, 2000).

It is also evident that children do not spontaneously use observational records in order to plan experimental strategies or to track data (Garcia-Mila & Andersen, 2007; Gleason & Schauble, 2000; Schauble, 1990), even when doing so positively correlates with experimental success (Siegler & Liebert, 1975). Nor do children spontaneously review or refer to observational records in order to derive meaning from experimental outcomes (Gleason & Schauble, 2000; Haslam & Gunstone, 1998; Klahr & Dunbar, 1988; Schauble, 1990). More often than not, children base inferences upon their own recall of events (D. Kuhn et al., 1995; Schauble, 1990) or from adult guidance (Driver, 1983; Gleason & Schauble, 2000; Haslam & Gunstone, 1996, 1998; Roth et al., 1997).

Even when children do record observations, their records do little work to support the development of scientific knowledge and reasoning. Keys (1999) noted that children fail to relate their observations to new hypotheses or knowledge claims. The missed opportunity for connecting recorded observations and scientific concepts may be due, in part, to the fact that children's observational records typically include information that is incomplete (Garcia-Mila, Andersen, & Rojo, in press; Haslam & Gunstone, 1998) or irrelevant to the experimental goals (Roth & McGinn, 1998; Schauble, 1990). We see evidence of this in a study by D. Ford (2005) in which third graders wrote highly detailed descriptions of rock and mineral samples yet made few associations between their observations and deeper geological concepts. Their observations were both incomplete—individuals typically mentioned less than half of the eight possible observable properties—and featured geologically irrelevant properties (e.g., smell) and details unique to individual specimen (e.g., "mud on the bottom") rather than meaningful geological patterns (e.g., striations, layers). Interestingly, children's use of everyday language also constrained understanding, such as when children's use of shape descriptors reflected everyday meaning (i.e., form) rather than geological meaning (i.e., cleavage). Sometimes children ignored the observed evidence and focused on making assertions and comments, suggesting they understood neither the purpose of observational records (Garcia-Mila et al., in press; Keys, 1999) nor the role of evidence in scientific argumentation.

Why is it so difficult for children to generate and use productive observational records that support scientific reasoning? Some research suggests that developmental constraints may be at work. After all, older children are more likely than younger children to generate notations and to produce notations that are increasingly recognizable, accurate, and complex and that increasingly support problem solving and communication purposes (Eskritt & Lee, 2002; Triona & Klahr, 2006). Older children are also more likely to possess sufficient metacognitive awareness to recognize a need for creating and using memory aids (Garcia-Mila et al., in press; Siegler & Liebert, 1975).

However, there is substantial evidence to suggest that limited knowledge plays a more critical role (Roth & McGinn, 1998). Consider that the challenge of generating and using productive records is also common among older children and adults (Duschl et al., 2007). Children may simply not understand what is important to record due to lack of disciplinary knowledge, making the identification of features or properties arbitrary, something students participating in Classroom FeederWatch possibly sensed when they judged their observations to be of little use to ornithologists. Likewise, other factors associated with knowledge may be at play, such as vague educational goals or research tasks (Driver, 1983; Triona, 2004), insufficient explanation about the record's purpose or protocol (Trumbull et al., 2005), and learner beliefs about the nature of science in which observations are perceived as fixed rather than subject to challenge (Norris, 1984; Smith & Reiser, 2005).

To summarize, children's observations appear powerful in some cultural contexts (e.g., everyday activity) but weak and underpowered in others (e.g., informal or formal science). Children often attend to isolated instances of salient features and processes, which limits opportunities for connecting knowledge and building understanding of complex phenomena. It is very challenging for children to coordinate their expectations with observational evidence, particularly in environments that are complex or in which their expectations are especially robust. To be fair, this portrait is of children observing under knowledge-lean conditions, whereas authentic scientific observation is always situated in the context of disciplinary knowledge and practice (Daston & Vidal, n.d.; Norris, 1985). This is clearly a continuum, and our intention here is to mark the ends of the continuum in order to understand the distinctiveness of scientific and everyday observation (M. Ford, 2008). Recognizing how they are different is an essential first step toward envisioning how the distance between the two might be bridged.

Learning to Observe More Scientifically

So can children learn to observe and reason more like scientists? Our review of the developmental and educational literatures might suggest that the answer is no. Although they are often curious from an early age, and though they may learn some things through observation in ways that bear some interesting parallels to science, we see little evidence that most of children's observations are what we might consider scientific. Children may observe the things that interest scientists (e.g., plants, animals, insects), but the way children observe and the ways they use their observations to make inferences are not necessarily scientific.

However, we argue that children can indeed observe more scientifically when they learn in contexts that reflect disciplinary practice and support trajectories that connect their everyday observations with disciplinary knowledge. Too often in the psychology literature and in educational settings, children are asked to observe, compare, and describe phenomena without adequate preparation (e.g., D. Ford, 2005). Doing so "belies the complexity and depth of disciplinary knowledge and reasoning associated with scientific observation" and ultimately produces "the minimal possibility of subsequent elaboration of deeper scientific knowledge" (Metz, 1995, pp. 118–119). Disciplinary knowledge, however, is not enough for children to successfully develop as scientific observers. They also require supportive learning environments and tools.

What would it look like if children were to make a transition from everyday to scientific observation? And how might this transition be facilitated? To address these questions, we have constructed an observation framework, using birds as an exemplar organism (Table 1).

The continuum between everyday and scientific observation is represented by left to right movement across the columns. The left column summarizes our review of the children's scientific thinking literature and suggests specifics about where children start their journey from everyday to scientific observation. The right column summarizes our review of the expert literature and represents the end point of disciplinary practice. The middle column represents a set of hypotheses about how this journey occurs and some of the specific activities that may lead to progress.

The four rows in the table specify the core components of scientific observation. The first row, Noticing, is both perceptual and cognitive. As children move from everyday to scientific observation, the categories of what they notice about the world are more likely to correspond to those of a scientific discipline. Observations become more frequent and are more likely to be attached to labels that have scientific significance. The second row, Expectations, refers to the extent to which children coordinate their observations with big ideas and scientific theory. As children become more knowledgeable about a discipline, the ways they collect observations and the inferences they make from observation become more nuanced, explicit, and connected. The third row, Observational Records, refers to the cognitive, physical, and virtual tools that children use to record and reason with observational data. As children become more expert observers, they are more likely to document their observations and to use a variety of representations to organize their observations. The fourth row, Productive Dispositions, refers to the extent to which children engage in sustained observation over time and in a variety of contexts.

Our purpose in constructing the framework is to organize a set of testable hypotheses about what intermediate states and activities facilitate the transition from everyday to scientific observation. In the following, we review some of the existing literature that supports the idea that given a supportive environment, children can develop the interest, knowledge, and skills that are necessary to make this transition. Although the existing literature does not map exactly to the four observation competencies, it does inform us about important design choices that can support disciplinary thinking and practice. Very few of the studies we cite in the following focus only on observation. However, children in these examples begin by making purposeful observations of biological phenomena and then, through a supportive and adult-scaffolded process, begin using these observations as a basis for investigation, argument, and explanation. This process typically involves building an intergenerational community of learners who co-construct shared knowledge, experiences, and skills. In this process, children explicitly learn to use the tools (e.g., comparison, questions, argumentation) and the representations (e.g., descriptions, graphs, maps) of a particular science. This general description of a learning environment is a model of science-as-practice—learners are engaged in authentic scientific thinking using real objects, tools, representations, and forms of argument and theory building (Lehrer & Schauble, 2006).

TABLE 1
Observation framework

	Everyday observation (novice)	Transitional (intermediate)	Scientific observation (expert)
Noticing	Notice a bird is different from other organisms Notice more irrelevant than relevant features that distinguish one kind from others without explicit awareness Describe few features that may or may not conform to disciplinary structure Name kinds of birds, but naming doesn't do a lot of work	Notice more relevant features and identify patterns of features Use and describe features validated by others to identify birds (e.g., field guides) Connect features to function and behavior Name more kinds of birds Noticing stimulates related knowledge Name and organize birds into groups by function and/or behavior (e.g., birds of prey, shorebirds) Develop habits of attention that are more disciplinary specific than general	Notice & describe relevant features and ignore irrelevant features using disciplinary structure (e.g., taxonomy) Chunk observational information and use smaller search space to notice and group birds Name more kinds of birds and at higher hierarchical levels Identification and naming fits birds into complex system and is related to complex relationships Stimulate related knowledge Infer function and behavior from morphology
Expectations	Vague expectations about observations Confuse observational evidence with one's beliefs	More explicit expectations about birds that reflect plausible observations Explanations vary between being more scientific and more everyday	Explicit hypothesis consistent with a theoretical framework shapes observation, search space, and documentation Skilled coordination of hypothesis and evidence

(continued)

TABLE 1 (continued)

	Everyday observation (novice)	Transitional (intermediate)	Scientific observation (expert)
Observation Records	Observe without collecting or recording observations May cite a few factoids about a species	Record observations (e.g., use a personal list or journal) but begin to do so within disciplinary guidelines Compare personal data with other kinds of data Begin to use different representations of data	Record observations using established disciplinary procedures, standards, and representations Organize and analyze recorded observations Reason with observational data and representations
Productive Dispositions	Opportunistic and incidental observations Notice information about birds when it's easily available	Sustained engagement Intentionally talk about or seek information and observations about birds Collect biological objects and related paraphernalia	Persistent, sustained engagement Love the organism

Learning to Notice and Reason Scientifically

The transition from noticing phenomena through one's own "conceptual spectacles" to observing scientifically principally occurs through participation in shared practices and, importantly, shared conversation. Children learn to coordinate expectations and observational evidence when they start to think about, talk about, and publicly organize their observations and knowledge in ways that are consistent with a disciplinary learning community.

This could happen in either a formal or informal setting, but it has been studied most extensively in the context of schools. For example, Lehrer, Schauble, and colleagues (Lehrer & Schauble, 2001, 2004; Lehrer, Schauble, Carpenter, & Penner, 2000; Lehrer, Schauble, & Petrosino, 2001) described a series of design experiments where elementary students learn to use observation, argumentation, and inscription in ways that are increasingly consistent with disciplinary practice. In one study (Lehrer & Schauble, 2004), students began by directly observing and recording the height of a set of plants over several weeks. The teacher eventually posted all of the students' measurements and instructed them to organize and display the data so that it characterized the typical height of all the plants on a certain day. Working in small groups, students debated how to think about and represent the changes in growth before inventing ways to graph the data. Although each group established its own norms, those norms were then tested against other norms in public critique when groups reported to the whole class. Students debated the strengths and trade-offs of their representations and then modified them in response to critiques. Through an iterative process of creating, explaining, critiquing, and modifying each representation, students came to "observe" and describe plant growth in ways that direct everyday observation could not support. Lehrer and Schauble (2004) described how the students began to think about their observations as data and gained a new understanding of plants as populations rather than as single cases.

Other studies of argumentation have focused specifically on question asking—an important heuristic used by biologists to navigate a complex world. A study by Smith and Reiser (2005) provides insight into how question asking can be used to help students decompose and make sense of biological complexity. Working within a behavioral ecology framework, high school students used video data and computer software to observe and compare predator–prey behaviors of lion hunts. Question asking featured prominently among the various scaffolds. For instance, the teacher and the video software repeatedly modeled disciplinary specific how- and why-questions, which in turn spurred an iterative cycle in which students noticed features and behaviors, asked more questions, and then reexamined and refined their observations across multiple video examples.

Differences between pre- and posttest performance suggested that question asking enabled students to notice critical features and behaviors that supported richer explanations. Specifically, their explanations identified and incorporated significantly more morphological and behavioral features to account for animal behavior after participation. The iterative nature of question asking and observation also contributed to noticing recurring patterns and variations across multiple videos. For example, they compared animals of prey performing similar behaviors, such as stalking and chasing, and came to notice variations in how male and female animals captured prey. In contrast to everyday observers, these students filtered irrelevant evidence, focused on critical behaviors and features, and came to use the data as an aggregate rather than as unrelated instances.

Question asking is also an important strategy for engaging young children in noticing the world around them. More often than not, these questions originate from children's interests and their observations of familiar biological organisms—rodents and crickets in Metz (2000, 2004) and apples and fruits flies in Lehrer et al. (2001). One challenge that teachers faced in these studies was to strike a balance between children's questions and the demands of the discipline. The teachers in Metz's studies designed the environment so that children explicitly generated questions by observing animal behavior while they simultaneously learned zoological content and observational practices. Based upon their practical and content knowledge, the second and fourth/fifth graders then collectively created taxonomies of animal behaviors, which resulted in noticing more specific behaviors and generating new questions. By the end of the program, the majority of students used disciplinary heuristics to generate questions. In contrast, the teacher in the Lehrer et al. study designed the environment so that children's questions were drawn from direct observations of phenomena and spirited classroom discussions.

Throughout, the teacher carefully listened to children's comments and revoiced these into questions that reflected problems in plant biology. Similar to the prior examples, question asking motivated a cycle of observation and investigation that led to the generation of new questions.

These studies share a serious commitment to discourse and building classroom practice around the notion that talking science is necessary for doing science (Bell, 2000; Brown & Campione, 1994; Hogan, Nastasi, & Pressley, 2000; Lemke, 1990). Talk is useful in creating shared labels that organize observation events (Law & Lynch, 1990). Talk is useful in shaping shared questions that stem from awareness of authentic disciplinary content, problems, and practices (Finley & Pocovi, 2000; Norris, 1984; Trumbull et al., 2005). Talk is useful because it makes expectations explicit, which facilitates theory change (D. Kuhn, 1989; Ohlsson, 1992). Talk is useful because it is part of argumentation, the core activity by which scientists make public their reasoning, explain their evidence, and critique each other's theories (Bazerman, 1988; Dunbar, 1995; Duschl & Osborne, 2002; M. Ford, 2008; Rouse, 1996). Learning to observe scientifically is clearly much more than acquiring a perceptual skill—it is an act of joining a scientific community that uses observation to argue about the fundamental organization of nature.

Learning to Create Observational Records

Although the earlier review of the literature convincingly demonstrated that children typically do not create scientific records, examples from the research of Lehrer and Schauble (2001, 2004; Lehrer et al., 2000) as well as Metz (2000, 2004) suggest that children can and do generate observational records under certain conditions. Three factors appear to be critical to doing so: (a) the extent to which the record or inscription explicitly solves a problem that interests the child, (b) whether children use their own system of recording or whether they use systems created by others, and (c) mediation by those with more experience.

In order for children to generate field notes and to transform these into new formats, the problem must be authentic (Chinn & Malhotra, 2002b). That is, observation of phenomena must be in the context of a problem that is of interest to the child. For instance, during an investigation of rot, first graders noticed the emergence of fruit flies in their classroom and throughout the school (Lehrer et al., 2001). Concern for where the fruit flies had come from spurred a population count throughout the school, which resulted in the repurposing of a school map and color-coding the locations of varying concentrations of fruit flies. Comparing these concentrations, students concluded that food and water might affect the concentrations and set up an experiment to test their expectations. Thus, young children can and do transform observations into new formats when engaged in solving problems that they help to define.

Children's understanding and use of observational records improves when they generate their own notational systems rather than simply use an existing system (diSessa, 2004; Roth & McGinn, 1998; Triona, 2004). Equally important, when children have multiple opportunities to create, critique, and revise their notations, they also build complex bases of domain knowledge (Lehrer & Schauble, 2006). Recall, for example, that students who invented and critiqued their own inscriptions also came to observe plants as populations (Lehrer & Schauble, 2004).

Because the generation and use of observational records is a learned practice, mediation by a more experienced person is essential. Clearly, teachers serve this role in the classroom. In everyday contexts, parents support young children's notational habits by helping them to understand which features are important to include and how well their notations communicate the intended purpose (Braswell & Callanan, 2003). However, in everyday contexts, children may be more likely to use, rather than to generate, observational records. Consider that E. O. Wilson used field guides as a teenager, in the company of a friend who shared his enthusiasm for butterflies. In this situation, field guides functioned as the disciplinary authority and mediated Wilson's observations by drawing attention to disciplinary features and ways of noticing in the field.

Developing Productive Dispositions

As previously noted, the interests and identity of individual biologists can drive their habits of attention and pursuit of knowledge. So, it may not be such a leap to imagine that children who develop robust interests also tend to look for and seek information about the objects that interest them. Metz (2004) noted this pattern when she attributed children's tendency to observe closely and to engage deeply for extended periods when they pursued their own questions about the behaviors of rodents and crickets.

What supports the emergence and persistence of children's interests? To address this question, we once more turn to Stephen Jay Gould (2002), who reflected on the motivations of observational scientists to study the natural world:

> We become natural historians because we loved those dinosaurs in museums, scrambled after those beetles in our backyard, or smelled the flowers of a hundred particular delights. Thus, we yearn to know, and cannot be satisfied until we do, both the general principles of how mass distinction helps to craft the patterns of life's history, and the particular read on why Pete the *Protoceratops* perished that day in the sands of the Gobi. (p. 1338)

Although this is the reminiscence of an expert scientist, we think that Gould's comments offer insight into the development of biological interest generally. First, objects—be they beetles, flowers, or dinosaurs—are powerful sources of inspiration for observation and the desire to know more. Objects are often the catalysts that inspire opportunistic situational interest, but under the right conditions, can also support individual interest that fuels persistent, sustained engagement (Leibham, Alexander, Johnson, Neitzel, & Fabiola, 2005; Renninger, 1992). Recall D. Ford's (2005) study of third graders learning about geological rocks and minerals. An interesting thing happened as these children observed and described the study samples week after week: Some children began claiming samples as "my rock" and "my mineral." Whenever possible, they purposely sought "their rock" from the sample set, imbued "their rock" with meaning, and carefully noted unique characteristics in order to recognize "their rock." Ford interpreted this behavior as a nuisance, pointing out that such personalization might interfere with "real" scientific reasoning. The concept of productive dispositions makes us think the opposite might be true.

Second, Gould's (2002) reflection also suggests something about the necessity for opportunity and external support to form and sustain individual interests. It would seem that Gould enjoyed generous access to nature and to scientific collections.

Similarly, E. O. Wilson (1995) attributed his interest in biological organisms to long days wandering around the countryside or in the National Museum of Natural History, often simply looking for hours at a time. And biologist James D. Watson attributed his early interest in biology to sharing bird watching activities, knowledge, and experiences with his father throughout his youth (Friedberg, 2004).

Time to look is probably a necessary condition to develop a productive disposition, and is often a rare commodity in classrooms. Thus, it is not surprising that the studies that come closest to mapping the development of productive dispositions occur in informal settings. Museums, books, nature walks, the Web, and after-school settings are all places where children have been described as developing knowledge and interest about scientific topics (e.g., Crowley & Jacobs, 2002; Johnson, Mervis, Spencer, Leibham, & Neitzel, 2004; Korpan, Bisanz, Bisanz, & Boehme, 1997; Palmquist & Crowley, 2007). We are just beginning to understand how to track learning and development across such settings (e.g., Barron, 2006). This strikes us as an area of research that needs much more attention.

Conclusion

In this article, we have argued that authentic scientific observation is a complex and challenging enterprise that is always practiced within a disciplinary framework. The science education and developmental psychology literatures suggest that everyday and scientific observers notice, filter, and reason about the natural world differently: When in the hands of expert observers, observation plays a key role throughout the inquiry process, whereas everyday observers tend to apply observation primarily in the service of data collection. We have also argued that children can develop as scientific observers when they have the knowledge, tools, and experience to support their reasoning.

In order to explore how children learn to observe more scientifically, we have proposed an observation framework for thinking about how this transition might occur and presented examples that suggest hypotheses of what this transition might look like. Four qualifications seem important to note. First, each component described in the framework functions as part of a system, so that changes to one necessarily affect another. For instance, a child's emerging interest may stimulate finding out something about a specific organism, which in turn may inspire asking new questions and noticing specific features or behaviors. Second, the intent here is not that young children become expert scientific observers, but that their observations can become increasingly more powerful, productive, and scientific in educational settings.

Third, although this journey began by reflecting upon the observation of birds during a school activity, the proposed framework is a general statement about scientific observation that would hold true across formal and informal learning contexts. Essentially, we have described a learning trajectory for the practice of scientific observation that may occur wherever and whenever children engage with natural phenomena. We offer the proposed framework as a tool for thinking about observation in the context of disciplinary practice and as a roadmap for future research.

Our final qualification revolves around the question of how specific the proposed framework is to biology. Some parts are quite specific. After all, disciplinary practice imposes constraints upon observation. Concepts such as species, kinds, and organisms are unique to biology, as are the behaviors of collecting biological objects or "loving the organism." It would be relatively easy, however, to imagine substituting concepts such as "properties" or behaviors such as "love the rocks" to adjust the framework to the demands of geological disciplines. However, other parts of the framework may be applied more generally. The four components of scientific observation—noticing, expectations, observational records, and productive dispositions—and the three states of observation—everyday, transitional, and scientific—generalize across scientific domains. We might also expect that an individual's unique combination of experiences, opportunities, and interests shapes how individuals move through a learning trajectory.

Notes

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1. Our depiction of children as observers suggests that they often start with organisms as the main focus of attention. However, recent research by Bang, Medin, and Atran (2007) reminds us that this assumption, too, reflects the culture in which children live. In indigenous rural populations, children sometimes develop mental models of nature that are ecologically oriented rather than beginning with organisms.

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