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Shared Scientific Thinking in Everyday Parent--Child Activity

KEVIN CROWLEY
Learning Research and Development Center, University of Pittsburgh, LRDC Building, 727, 3939 O′Hara Street, Pittsburgh, PA 15260, USA

MAUREEN A. CALLANAN
Psychology Department, University of California, Santa Cruz, USA

JENNIFER L. JIPSON
University of Michigan, Ann Arbor, USA

JODI GALCO
Learning Research and Development Center, University of Pittsburgh, USA

KAREN TOPPING
Psychology Department, University of California, Santa Cruz, USA

JEFF SHRAGER
Department of Plant Biology, The Cornegie, Institution of Washington, USA

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ABSTRACT: Current accounts of the development of scientific reasoning focus on individual children's ability to coordinate the collection and evaluation of evidence with the creation of theories to explain the evidence. This observational study of parent–child interactions in a children's museum demonstrated that parents shape and support children's scientific thinking in everyday, nonobligatory activity. When children engaged an exhibit with parents, their exploration of evidence was observed to be longer, broader, and more focused on relevant comparisons than children who engaged the exhibit without their parents.

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Parents were observed to talk to children about how to select and encode appropriate evidence and how to make direct comparisons between the most informative kinds of evidence. Parents also sometimes assumed the role of explainer by casting children's experience in causal terms, connecting the experience to prior knowledge, or introducing abstract principles. We discuss these findings with respect to two dimensions of children's scientific thinking: developments in evidence collection and developments in theory construction.
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INTRODUCTION

This study explores the role that parents play in structuring children's everyday scientific reasoning and in facilitating the construction of children's everyday scientific theories. Research on out-of-school scientific thinking has often focused on either the processes through which children collect evidence and construct theories (Klahr, Fay, & Dunbar, 1993; Kuhn, 1989; Kuhn, Amsel, & O'Laughlin, 1988; Schauble, 1996) or the content and organization of children's theories in foundational domains such as physics, psychology, and biology (Carey, 1985; Gopnik & Meltzoff, 1997; Wellman & Gelman, 1998). Although work on these two dimensions of scientific thinking provides a detailed picture of what individual children can do in the context of laboratory-based psychology studies, little is known about spontaneous scientific thinking in everyday activity. In particular, current developmental theory is underspecified with respect to the role that parents may play in guiding children's scientific reasoning processes and in structuring children's creation and use of theories. In this paper, we address this issue through an analysis of spontaneous episodes of scientific thinking that occurred during family museum visits.

One major branch of research into children's scientific thinking has been concerned with scientific reasoning processes. Such studies have sought to describe how individual children form hypotheses, collect evidence, make inferences, and revise theories. The process of scientific thinking has been described as depending on the coordinated search of at least two problem spaces: a space of evidence and a space of theories (Klahr & Dunbar, 1988). These are seen as mutually interactive, so that inferences about evidence can modify theories and inferences drawn from theories can influence how individuals seek out further evidence.

Studies of children's self-directed problem solving suggest that children sometimes have difficulty in coordinating the collection of evidence with the construction of theories. For example, Schauble (1996) compared adults to fifth and sixth graders on a self-directed scientific reasoning task. Compared to children, adults explored the evidence more systematically and were more likely to make inferences about variables that they had originally misunderstood. When children interpreted evidence, they were more likely to focus on the effects of variables that they had already understood correctly. Similarly, Dunbar and Klahr (1989) found that, compared to adults, children generated less informative comparisons and often jumped to incorrect conclusions before conducting an exhaustive search of available evidence. One of the reasons younger children are thought to have difficulty at coordinating evidence and theory is that they often appear to have difficulty in separating a potential theory from the evidence that could prove or disprove it (Kuhn et al., 1988). The inability to separate the two is often thought to result from metacognitive lapses in reflection, and leads to situations where children are unable to adjust theories in response to evidence.

The first hypothesis we test in this study is that children's scientific reasoning processes are more advanced when parents and children jointly engage in scientific thinking. There is a growing literature concerning the ways parents shape children's problem solving in domains other than scientific thinking (see Rogoff, 1998 for a review). Wood, Bruner, and Ross (1976) first described parents as expert problem solvers who scaffold the novice problem solving of children by helping to define the task, simplifying subgoal structures, helping to maintain motivation, helping to identify appropriate outcomes, regulating frustration, and demonstrating expert solutions. Recent work inspired by sociocultural theory enriches the earlier scaffolding account by examining parent–child problem solving in light of how the mutually constituted activity contributes to the development of children's participation in specific cultural, historical, and institutional contexts (e.g., Rogoff, 1990). In this study, we extend this prior work to the question of how parent participation impacts children's everyday scientific reasoning by comparing the ways that children collect evidence when they are collaborating with parents, with peers, or when they are engaged in solitary reasoning.

A second major branch of scientific thinking research has been concerned with the content and organization of children's theories for foundational domains such as biology, physics, and psychology. For example, evidence suggests young children have developed an elementary understanding that biological entities share common defining characteristics that make them distinct from physical entities (Wellman & Gelman, 1998). Many of these "theory–theory" accounts emphasize the role of causal explanations in theory development and revision. Carey (1985), for example, argues that "explanation is at the core of theories" (p. 201). In most of the discussions within the theory approach, explanations are seen as a useful tool for assessing the nature of a child's current theory. Less attention has been given to the social context in which explanations are constructed, and to the possible role of children's everyday conversations about scientific topics as a setting within which theories are constructed and revised. Explanation episodes that arise in everyday conversation present excellent opportunities for children to articulate and revise their theories of scientific phenomena, with guidance from parents and other adults.

Thus, the second hypothesis we explore in this study is that parents explain science to their children while engaged in everyday scientific reasoning. Studies of picture-book reading have shown that parents provide children with information about labels and properties of objects, but less information about causal processes (Gelman, Coley, Rosengren, Hartman, & Pappas, 1998). Explanations and other scientific information seem to be more prevalent, however, when parents and children are involved in more active settings rather than in the reading and pretend play activities in which parent-child conversation has been most often studied. Several studies have reported that parents and children engage in meaningful explanatory conversations during dinner table conversations, cooking projects, and other activities (Callanan & Jipson, 2001; Callanan & Oakes, 1992; Shrager & Callanan; 1991; Snow & Kurland, 1996). Snow and Kurland (1996) examined parent–child conversations while playing with magnets and found parents' discussion of scientific processes was correlated with children's performance on several measures of early literacy. Snow and Kurland see scientific explanation as a kind of extended discourse, and argue that science talk in the home should prepare children for school science discussions.

MUSEUMS AS LOCATIONS FOR STUDYING EVERYDAY SCIENTIFIC THINKING

To capture everyday scientific thinking, we videotaped family interactions at an interactive science exhibit in the Children's Discovery Museum in San Jose, California. Similar to the computer microworlds or contrived laboratory tasks that have often been used in previous developmental studies of children's scientific thinking (Klahr, 2000), interactive science exhibits provide environments where children can generate evidence, interpret evidence, and build theories relevant to particular science or technology content.

Previous museum-learning research suggests that museum visits provide a good context for a study of family scientific thinking, as parents and children would be expected to engage in practices typical of everyday activity, such as agenda and goal negotiation, a mix of individual and social problem solving moments, and, importantly, conversation (Borun, Chambers, & Cleghorn 1996; Cone & Kendall, 1978; Dierking & Falk, 1994; Gelman, Massey, & McManus, 1991). Family conversations in museums have been characterized as a mix of specific talk about how to manipulate exhibits, describe concrete visible aspects of an exhibit, or to connect the museum experience to prior family experiences and memories (Falk & Dierking, 2000). Although individual museum exhibits are often not designed with a family audience in mind (Crowley & Callanan, 1998), families are more likely to collaborate and talk when exhibits have, among other features, multiple access points, a multiuser capability, multiple possible outcomes, and content that is directly relevant to visitors' prior knowledge and experiences (Borun & Dristas, 1997).

We focused on scientific thinking at a zoetrope in the Children's Discovery Museum (Figure 1). The zoetrope is a simple animation device developed in nineteenth-century Europe (Hayes, 1992), which produces the illusion of motion through a stroboscopic effect involving persistence of vision (the retina retains an individual image for about one-tenth of a second) and the Phi phenomenon (the visual system combines the series of successive individual images into a single smooth motion). The stroboscopic presentation of individual frames in the zoetrope is enabled by looking through the slots of the spinning drum. Cartoons, movies, and video ensure that the typical child is surrounded by the illusion of motion in everyday settings. The zoetrope provides an opportunity to explore how these familiar devices work.

Zoetropes are a common interactive science exhibit at museums around the world; this particular zoetrope had an additional uncommon feature. Above each frame of an animation

Figure 1. This study focused on families who used the zoetrope while visiting the San Jose Children's Discovery Museum. Visitors who spin the zoetrope and look through the slots see an animation of a running horse. Above each frame of animation is a tab that can be raised or lowered. When a raised tab breaks the beam of light in the photoelectric switch, a hidden speaker produces the sound of a horse hoof hitting the ground.

of a running horse there was a tab that could be raised or lowered by the visitor. A photoelectric switch is positioned above the rim of the zoetrope so that when a raised tab breaks the beam of light, it triggers the sound of a single hoof beat. Thus, in addition to exploring how the illusion of motion is created, children can experiment with constructing a "soundtrack" for the animation of the running horse.

What kinds of scientific thinking might occur if children happen to come upon a zoetrope during a museum visit? Children may decide to explore the illusion of motion. The primary operators of the zoetrope are spinning and stopping the drum, and observing through the slots or observing over the top. If children happen to look through the slots while the zoetrope is spinning, they will observe the illusion of motion. Once they have discovered how to produce the illusion of motion, two further aspects of the animation can also be explored. First, the direction in which the animated horse appears to be running depends on the direction in which the zoetrope is spun: Counterclockwise spinning makes the horse appear to run forward while clockwise spinning makes the horse appear to run backward. Second, the speed of the animation depends on how quickly children spin the zoetrope: Slow spinning makes the horse appear to run slowly while fast spinning increases the pace. Finally, in addition to exploring aspects of the illusion of motion, children might explore the zoetrope's tabs and photoelectric switch. By raising and lowering tabs and then spinning the zoetrope, children can create different patterns of sound. This could proceed independent of the animation, or it could be an attempt to synchronize the sound of hoof beats to the animation of the running horse.

To address the hypothesis that children's scientific-reasoning processes are more advanced when parents and children jointly engage in scientific thinking, we will compare the activity of children who used the zoetrope by themselves, in peer groups, or in parent-child groups. This level of analysis can be thought of as a baseline for describing the role of parents. Even if one takes the extreme position that all of the relevant developments in scientific thinking are best described as taking place solely within the mind of an individual child, it is relevant to have a description of the kinds of evidence children encounter and whether that evidence varies depending on the social context of activity.

Our second hypothesis was that parent conversation would support children's everyday scientific thinking. Thus, our second level of analysis describes how families talked about the evidence they encountered, including how children and adults suggested directions for exploration, described evidence, and explained. This level goes beyond the description of the evidence children encounter to a description of how collaborative activity may shape the way children encode, evaluate, and explain evidence they encountered in the course of everyday shared scientific thinking.

METHODS

Participants

Participants were 91 families with children between 4- and 8-years old who visited the Children's Discovery Museum in San Jose, California. Coding and analysis focused around the experience of one target children from each of these families. Our selection procedure for target children (described later) yielded a sample of 58 boys and 33 girls.

Data Collection

Data were collected on four separate days. A video camera was set up near the zoetrope and a wireless microphone was unobtrusively attached to the back of the exhibit. Researchers greeted families entering the museum, explained that they were videotaping as part of a research project, and asked families for written consent to participate. Consent rates were greater than 90% on each day of data collection. Children in consenting families wore large stickers identifying them as participants. This was the only point at which researchers interacted with visitors.

If a child wearing a sticker chose to engage the zoetrope during the natural course of his or her visit, the camera operator turned on the camera for the length of the engagement. Because the zoetrope is located in a room on the far side from the entrance of the museum, children typically do not encounter it until they have engaged many other exhibits. Thus, the initial rush of frenetic activity that is common when children first enter a children's museum had passed before children in this study engaged the zoetrope.

Data Reduction

Videotapes were segmented into nonoverlapping interactions. Even if families stay together as a group while visiting exhibits, each person does not necessarily arrive at a new exhibit at exactly the same time. For example, children sometimes run ahead to engage the next exhibit while parents and perhaps siblings linger behind at the previous one. Interactions were defined as beginning when the first child from a family—the *target child*—approached the zoetrope and are defined as ending when he or she left the zoetrope. The next target child was defined as the first child from a new family who engaged the zoetrope after all members of the previous target child's family had left. If children returned later to the zoetrope for a second engagement, they were not designated targets. Thus, each interaction analyzed in this study was a unique slice of time representing the complete engagement of a unique target child from a unique family.

The way in which children engaged the zoetrope determined whether they were in the adult–child, peer, or solitary group. The adult–child group was composed of the 49 families where children and parents were together as they engaged. The peer group was 22 families where two or more children engaged while parents were occupied elsewhere in the museum. Finally, in the solitary group, 20 children engaged by themselves while all other family members were occupied elsewhere in the museum.

The verbalizations and actions of all participants in each interaction were transcribed, with each transcript checked and verified by a second independent transcriber. Coding was conducted with both videotapes and transcripts. Reliability for each coding scheme was determined separately by comparing the codes of a primary coder with those of a second independent coder who processed at least 20% of the data. We report interrater agreement separately for each group of codes.

Target Children's Exposure to Evidence

General Measures of Engagement. In order to provide a broad comparison between the engagement of children in the parent–child, peer, and solitary groups, we computed the length of each target child's engagement and whether each target child has used each of the four basic operators afforded by the zoetrope. *Spinning* was coded if target children changed the state of rotation at least once by either spinning the zoetrope or stopping the zoetrope from spinning. *Observing through slots* was coded if target children looked for at least 2 seconds through the slots at least once. We adopted the 2-s threshold to ensure that children actually intended to look through the slots, as opposed to having simply passed their gaze past the slots while shifting their attention elsewhere. *Observing over the top* was coded if target children performed a 2-s gaze down into the cylinder of the zoetrope. *Using tabs* was coded if target children raised or lowered a tab at least once. Interrater agreement was 95%.

Perceiving the Illusion of Motion. Perceiving the illusion of motion depends on whether the zoetrope is spinning or not and on whether the viewer is looking at the frames of animation through the slots or over the top of the zoetrope. As described in Figure 2, the factorial combination of rotation state and observational vantage point defines four unique categories of evidence about the illusion of motion.

Each engagement was divided into 10-s segments and, for each segment, coders judged whether target children had visited each cell in the evidence space for at least 2 s. *SlotSpin* was coded if children looked at the animation through the slots of a spinning zoetrope, revealing the illusion of motion. *TopSpin* was coded when children looked down at the animation from over the top of the spinning zoetrope, revealing a spinning, but unanimated, sequence of frames. *SlotStop* was coded when children looked at the animation through the slots of a stopped zoetrope, revealing a single still frame. *TopStop* was coded when children looked down at the animation from over the top of a stopped zoetrope, revealing a sequence of still frames. Interrater agreement was 91%.

Changing the Speed of Animation. The speed of the animation depends on how quickly children spin the zoetrope: Slow spinning makes the horse appear to run slowly, faster spinning increases the pace. By coding differences in how the spinning zoetrope appeared on the videotapes, we determined whether children observed the animation through the slots for at least two continuous seconds while spinning was slow, medium, or fast. With *slow spinning* (about 40 rpm), the animation appears on the videotape to be in slow motion and individual slots and tabs can be clearly perceived. With *medium spinning* (about 70 rpm), the horse appears to be running at a normal speed, and the slots appear as static rectangular flashes (i.e., individual slots can no longer be distinguished as they rotate past). Individual tabs are still clearly distinguishable. With *fast spinning* (about 100 rpm), the animation becomes noticeably brighter and individual tabs can no longer be distinguished. A series of dark bands (caused by an interaction between the speeds of the rotating slots and the video camera shutter) appears to move smoothly across the animation in the opposite direction of the zoetrope's motion.

	Looking through slots	Looking over top
Zoetrope spinning	**SlotSpin** Observer sees the illusion of motion	**TopSpin** Observer sees a spinning series of separate frames
Zoetrope stopped	**SlotStop** Observer sees one still frame	**TopStop** Observer sees a series of still frames

Figure 2. Evidence relevant to the illusion of motion can be described as a factorial space determined by observational vantage point and rotational state of the zoetrope. The animation has a unique appearance in each cell of the space. By comparing the evidence available from different cells, children could collect sufficient evidence to understand how the zoetrope works.

Coding was conducted from videotapes with the sound turned off to ensure that any talk about speed of spinning or the patterns of sounds generated by raised tabs passing through the photoelectric switch did not influence coding judgements. Interrater agreement was 88%.

Reversing the Direction of Animation. The direction in which the animated horse appears to be running depends on the direction in which the zoetrope is spun: Counter-clockwise spinning makes the horse appear to run normally; clockwise spinning makes the horse appear to run in reverse. Coders judged whether the target child looked at the animation through the slots for at least two continuous seconds while the zoetrope was spinning in each direction. Interrater agreement was 100%.

Changing Patterns of Sound. If participants raised or lowered the tabs and then spun the zoetrope, they could hear different patterns of sound. Coders listened to the patterns of sound experienced by each target child and judged whether they heard one pattern or more than one. Interrater agreement was 92%.

Conversations and Parent Guidance

Using both transcripts and videotapes, we coded four kinds of talk for each participant in parent–child and peer groups. Target children who visited the zoetrope by themselves were not coded because they had no potential conversational partners.[1]

Describing evidence was defined as talk about the evidence that could be observed at the zoetrope that did not establish any causal, analogical, or principled connections between what could be seen and how or why it could be seen. Each utterance by each participant was coded for whether he or she had described evidence. Interrater agreement was 93%.

In addition, because we were interested specifically in parent guidance, parent activity was coded on a larger grain size for how descriptions of evidence functioned to shape children's scientific thinking. By examining the activity and conversation throughout the whole interaction, coders judged whether parents had used talk to (1) highlight a single kind of relevant evidence; and/or (2) suggest the correct encoding of evidence. Examples of these are presented later in the results section. Interrater agreement was 85%.

Giving directions was defined as talk about how to manipulate the zoetrope, such as, "Spin it this way," "You have to look through these slots," or "Let's raise these tabs." To be coded in this category, an utterance must have explicitly referred to one of the four operators. Each utterance by each participant was coded for whether he or she had given directions. Interrater agreement was 88%.

We also applied codes of a larger grain size to identify the extent to which parents guided children's exploration by giving directions. By examining the activity and conversation throughout the whole interaction, coders judged whether parents had used talk to (1) tell children how to generate a single kind of evidence; and/or (2) suggest direct comparisons between different kinds of evidences. Examples are presented later in the results section. Interrater agreement was 90%.

Explanation was defined as talk about causal relations, analogies, or general statements of the scientific principles underlying the exhibit. Causal explanations included talk about causal links within the local context of the exhibit such as "The horse looks like it's running backwards because you spun this thing the wrong way." Analogies included talk that made a

[1] It was logically possible that children alone may have talked to themselves, and, indeed, talk was coded in 15% of the solitary groups. In these cases, talk was always about observation (e.g., saying "Cool!" following the first successful perception of the illusion of motion).

connection between the exhibit and prior knowledge or prior experience such as "This is how cartoons work." Principles included talk about unobservable causal principles underlying, for example, the illusion of motion, "Your mind, your eye, put together each of these little pictures and that's why it looks like it's moving." Interrater agreement was 87%.

Other was used for utterances that could not be assigned to the three utterance-level codes as described earlier. We included this category in order to account for all talk in the interaction and thus be able to provide some context for the overall frequencies for the other three categories of talk. Among the kinds of talk coded as "other" were statements about turn-taking, safety, and talk unrelated to using the zoetrope such as needing to eat or visit the bathroom.

RESULTS

Results are presented in three parts. First, we compare the evidence encountered by target children in adult–child, peer, or solitary groups. Second, we compare general measures of talk from the utterance-level coding of adult–child and peer groups, describing how parents talked about evidence, encouraged children to explore, and explained. Because preliminary analyses revealed no systematic gender differences, findings are presented collapsed across gender.

The Evidence Children Encountered

General Measures of Engagement. Table 1 summarizes general measures of children's engagement with the zoetrope. Children who engaged the zoetrope with their parents spent significantly more time at the exhibit than children who engaged by themselves or in peer groups, $F(2, 88) = 12.77$, $p < 0.0001$.[2] Follow-up comparisons showed significant differences between the adult-child group and the solitary ($p < 0.0001$) and peer groups ($p < 0.001$), which were not significantly different from one another. The overall mean (62 s) and standard deviation (54 s) for engagement time are consistent with other studies of interactive science exhibits (Borun et al., 1996; Paris, Troop, Henderlong, & Sulfaro, 1994) and suggest that the particular zoetrope we studied is not atypical among interactive science exhibits.

TABLE 1
General Measures of Children's Use of the Zoetrope

	Children with Parents	Children with Peers	Solo Children
Time at exhibit(s)			
Mean	85	42	27
SD	59	27	30
Use of four operators			
Spin	85%	72%	100%
Look through slots	75%	54%	50%
Look over the top	55%	59%	60%
Use tabs	41%	32%	25%

[2] To compare continuous dependent measures, we used analysis of variance (ANOVA) with follow-up (Fisher PLSD) comparisons. The ANOVAs determined whether there was a reliable main effect for whether children used the zoetrope as part of a adult–child, peer, or solitary group. The follow-up analyses identified which of the pair-wise comparisons between these three groups was statistically significant at the 0.05 level or beyond. For discreet dependent measures, Chi-squares were used to determine whether the overall effect for group was significant.

Although children in adult–child groups spent significantly more time at the exhibit, they were not significantly more likely than other children to have tried out any of the four basic operators. In fact, members of the group that engaged the zoetrope for the shortest time, children by themselves, were most likely to have spun it at least once, followed by children with adults and in peer groups, χ^2 (df $= 2$, $n = 91$) $= 6.4$, $p < 0.05$. There were no significant differences in use of the other three operators. A little over half of the children looked over the top at least once, regardless of whether they were with parents, peers, or by themselves, χ^2 (df $= 2$, $n = 91$) $= 0.18$, n.s. Children with adults were somewhat more likely to look through the slots, followed by children in peer groups and alone, but the difference was only marginally significant, χ^2 (df $= 2$, $n = 91$) $= 5.4$, $p < 0.07$. Finally, less than half of the children manipulated tabs at least once, regardless of whether they were with parents, with peers, or by themselves, χ^2 (df $= 2$, $n = 91$) $= 1.7$, n.s.

Exploring the Illusion of Motion. To perceive the illusion of motion from the zoetrope, it is necessary to spin the zoetrope and observe the animation frames through the slots on the drum. To what extent did target children encounter the four categories of evidence—SlotSpin, TopSpin, SlotStop, TopStop—that could support such an inference (Figure 3a)? Each category of evidence was analyzed with one-way ANOVAs and planned Fisher PLSD comparisons between adult–child, peer, and solitary groups.

Children who used the zoetrope with their parents encountered evidence from each of these categories more often than children in peer groups or children alone (Figure 3b). For each category of evidence, the adult–child group was significantly higher than the peer and solitary groups, which were never significantly different from each other. For SlotSpin evidence, the main effect was significant, $F(2, 88) = 8.45$, $p < 0.001$, with the parent–child group significantly higher than the peer group, $p < 0.01$, and alone group, $p < 0.001$. For SlotStop evidence main effect was significant, $F(2, 88) = 4.06$, $p < 0.05$, with the parent–child group significantly higher than the peer group, $p < 0.05$, and alone group, $p < 0.05$. Similarly, for TopStop evidence the main effect was significant, $F(2, 88) = 6.67$, $p < 0.01$, with the parent–child group significantly higher than the peer group, $p < 0.01$, and alone group, $p < 0.01$. Finally, the ANOVA for TopSpin evidence also showed a significant main effect, $F(2, 88) = 4.88$, $p < 0.01$, with the parent–child group significantly higher than the peer group, $p < 0.05$, and alone group, $p < 0.01$.

The factorial evidence space (Figure 3a) specifies six "experiments" children could have conducted while using the zoetrope. For example, consider a child who looks through the slots of a spinning zoetrope to perceive the illusion of motion (SlotSpin), and then, with the zoetrope still spinning, looks over the top and perceives a spinning series of nonanimated frames (TopSpin). This is a controlled comparison with one variable (observation vantage point) manipulated and one variable (spinning) held constant. Comparing the two outcomes provides evidence to support the inference that looking through the slots is necessary to perceive the illusion of motion. We defined children as having conducted an experiment if they collected the relevant pair of observations within the same 10-s segment.

Figure 3c shows the mean number of paired comparisons performed by children in each group. As we report later, all significant differences involved the adult–child group showing higher performance than the peer and/or solitary groups, which were never significantly different from each other.

As suggested at the left of Figure 3c, children with adults were significantly more likely than other children to compare the condition where the zoetrope produces the illusion of motion (SlotSpin) to the three conditions where it does not (TopSpin, SlotStop, and TopStop). There was a significant main effect for group on SlotSpin vs. TopSpin

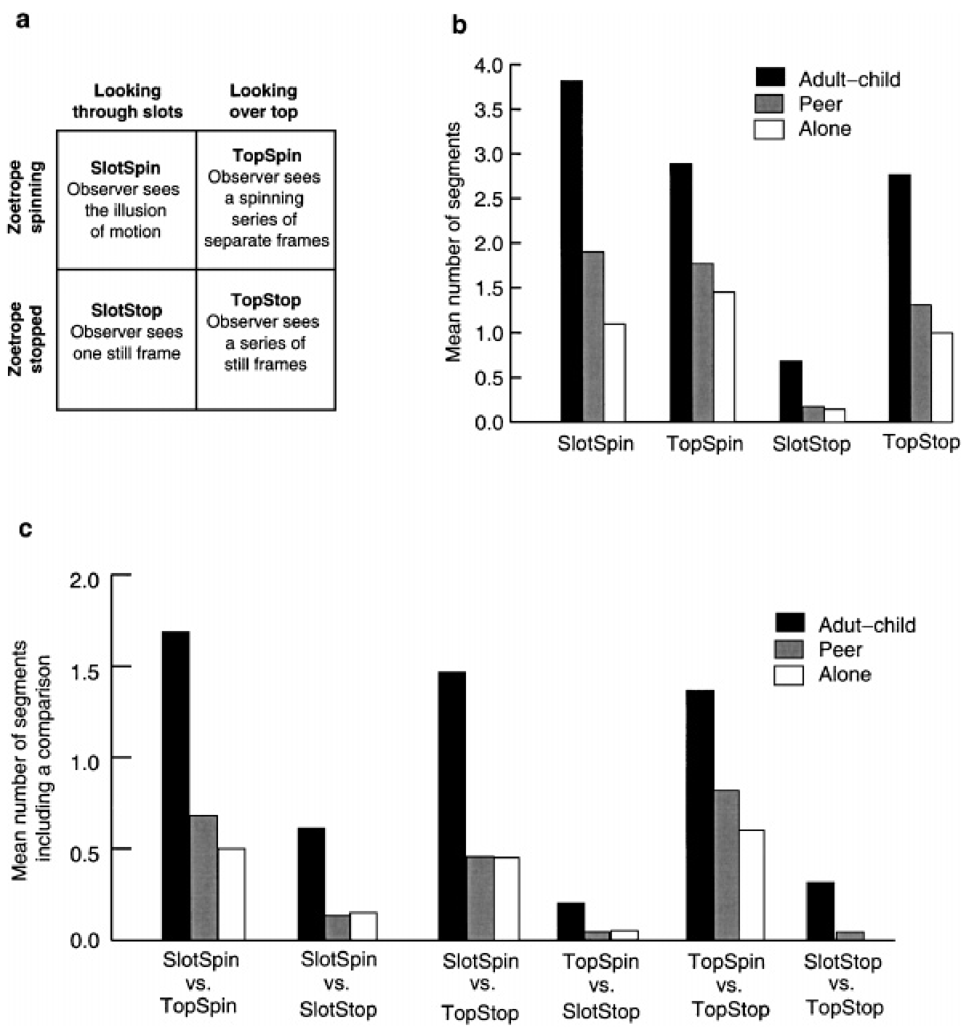

Figure 3. (a) Target children's exposure to evidence about the illusion of motion was described as the mean number of 10-s segments in each interaction where children entered each cell in the factorial evidence space, (b) Children in adult–child groups encountered each kind of evidence more often than children in peer or solitary goups, and (c) were more likely to make comparisons between two cells in the evidence space within a single segment.

comparisons, $F(2, 88) = 6.68$, $p < 0.01$, with the adult–child group significantly higher than the peer group $p < 0.01$, and solitary group, $p < 0.01$. For SlotSpin vs. SlotStop comparisons, there was a significant main effect, $F(2, 88) = 3.49$, $p = 0.05$, with the adult–child group significantly higher than the peer group, $p < 0.05$, and the solitary group, $p < 0.05$. Finally, for SlotSpin vs. TopStop comparisons there was also a main effect for group, $F(2, 88) = 5.29$, $p < 0.01$, with the adult–child group significantly higher than the peer group, $p < 0.01$, and the solitary group, $p < 0.05$.

The other three paired comparisons do not involve SlotSpin evidence, and thus do not involve the illusion of motion (right of Figure 3c). Although children with adults still exhibited the highest mean numbers of comparisons, main effects for group were only significant for SlotStop vs. TopStop comparisons, with a main effect of $F(2, 88) = 6.01$, $p < 0.01$, and the adult–child group significantly higher than children in peer groups, $p < 0.05$, or solitary groups, $p < 0.01$. Main effects were not significant for the other two kinds comparisons: TopSpin vs. SlotStop, $F(2, 88) = 2.05$, n.s., and TopSpin vs. TopStop, $F(2, 88) = 2.6$, n.s.

Thus, compared to children with peers or children alone, children with their parents were exposed more often to the four kinds of evidence and they were more likely to conduct paired comparisons of the conditions under which the zoetrope does and does not produce the illusion of motion. The finding that the pattern of differences were not as pronounced for comparisons that do not involve the illusion of motion suggests that the presence of parents was not just associated with an increase in any of the possible comparisons. Instead, children with parents focused more frequently on the most informative group of comparisons.

Changing Speed and Direction of Animation. Once children understand how to create the illusion of motion with the zoetrope, there are two further aspects of the illusion that can be directly explored: the relation between the direction of spin and the direction in which the horse appears to run, and the relation between spin rate and the speed with which the horse appears to run.

To explore the relation between direction of spin and direction of animation, children would need to have observed the animation through the slots at least once when the zoetrope was spinning clockwise and once when it was spinning counterclockwise. Target children in adult–child groups (37%) were somewhat more likely to have observed both pieces of evidence at least once, followed by children in solitary groups (25%), and in peer groups (9%), χ^2 (df $= 2$, $n = 91$) $= 6.17$, $p = 0.05$.

To explore the relation between rate of spin and speed of animation, children would need to have observed the animation through the slots when the zoetrope was spinning at two different speeds. Children were equally likely to have observed at least two different speeds of animation, regardless of whether they were in the adult–child group (33%), peer group (36%), or solitary group (30%), χ^2 (df $= 2$, $n = 91$) $= 0.20$, n.s.

Changing Patterns of Sound. By raising and lowering tabs and then spinning the zoetrope, children could make the zoetrope generate different patterns of sound. As noted in earlier analyses, raising or lower tabs was the least explored of the four possible operators, with less than half of children from each group manipulating the tabs. However, target children would have encountered evidence that the tabs could be used to make different patterns of sound regardless of whether they themselves had raised the tabs or whether tabs were raised by other people using the zoetrope with them. A broader analysis measured the number of different sound patterns that children heard during engagement, either because they or another person had manipulated tabs and then spun the zoetrope. Children in parent–child groups were the most likely to hear more than one pattern of sound (49%) followed by children in peer groups (41%) and children alone (10%), χ^2 (df $= 2$, $n = 91$) $= 9.19$, $p = 0.01$.

Raising the tabs to make different patterns of sound could occur independently of the animation, or it could have occurred in the context of families trying to synchronize the patterns of sound to the animation of the running horse. To look for evidence of synchronization, coders went back to examine segments where families raised or lowered at least one tab and judged the family as having engaged in synchronization if they talked about synchronization or showed any evidence of synchronization in manipulation patterns. Only two interactions (one parent–child and one peer) contained any evidence of synchronization.

In both of these cases participants explored it for less than 20 s, failed to make significant headway, and abandoned the goal.[3]

Comparing General Characteristics of Talk between Adult–Child and Peer groups

While engaged with the zoetrope, target children in adult–child groups (92%) were more likely to be involved in talk—defined as generating talk, hearing talk, or both—than target children in peer groups (73%), χ^2 $(1) = 4.58$, $p < 0.05$. Furthermore, talk in parent–child groups was more likely to be mutual than talk in peer groups. Of the 92% of parent–child interactions involving talk, 92% involved both parents and target children generating some of the talk. In contrast, among the 73% of peer interactions that included talk, only 44% involved both target children and other children generating some of the talk, $\chi^2(1) = 6.37$, $p < 0.05$. Thus, the majority of cases where talk occurred in peer group interactions were characterized by one child speaking and the other not responding.

As shown in Figure 4, adults were more likely than children to engage in each of the four kinds of talk coded. Because there could have been multiple adults and children in each interaction, the data in Figure 4 are adjusted to show the mean speech act per adult or child in each interaction. First, consider adults and children who visited the zoetrope together. Although

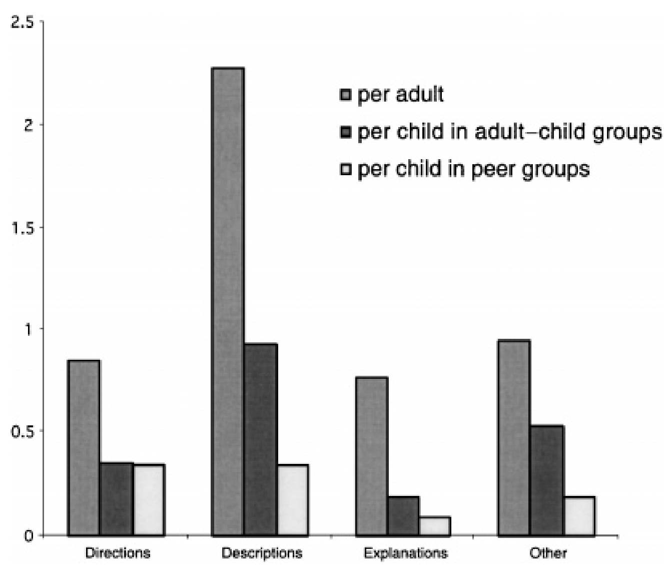

Figure 4. Mean utterances of each kind for adults and children. As compared to children in adult–child interactions or children in peer interactions, parents carried most of the conversation that arose at the zoetrope.

[3] It is not surprising that children were unsuccessful at achieving synchronization as it is quite subtle. With their permission, we recorded two adults without children spend almost 10 min engaged in discussion and experimentation trying to synchronize sounds and animation. It was difficult even for the adults. They followed the sensible strategy of raising tabs above each frame where a hoof was depicted as hitting the ground. However, this strategy only works when one observes the animation directly across the cylinder from the photoelectric switch, because each sound of a hoof beat is then generated at the moment when the animation shows the hoofs falling. Observing from another spot puts the animation and the soundtrack out of synchronization. The adults did not realize this at first, 2 most of the 10 min trying to figure out why their initial strategy did not work.

the finding that adults were more likely to talk about how to manipulate the zoetrope was marginally significant, $t(48) = 1.84$, $p = 0.07$, adults were significantly more likely than children to describe evidence, $t(48) = 3.317$, $p < 0.01$, offer explanations for the zoetrope, $t(48) = 3.53$, $p < 0.001$, and engage in other types of talk, $t(48) = 2.24$, $p < 0.05$.

Now consider how the context of interacting with adults vs. peers affected the nature and amount of children's talk. Figure 4 shows that children in adult–child interactions were no more likely than children in peer groups to talk about how to manipulate the zoetrope, $t(69) = 0.01$, n.s., marginally more likely to describe evidence, $t(69) = 1.7$, $p = 0.08$, no more likely to explain, $t(69) = 0.79$, n.s., and significantly more likely to engage in other types of talk, $t(69) = 2.44$, $p < 0.05$.

Thus, parent–child groups contained the most talk and parents were primarily responsible for carrying the talk. We turn now from general measures of talk to the functional coding of how parent talk framed children's interpretation of evidence, guided children's exploration, and suggested explanatory links.

How Parents Supported Children's Scientific Thinking

Parents Helped Children Select and Encode Relevant Evidence. One of the difficulties children face in everyday scientific thinking is to decide which parts of the ongoing rush of experience are relevant evidence and which are not. In 47% of interactions, parents highlighted evidence by labeling the relevant effect on which children should focus. This most often took the form of brief "play-by-play" commentary or questions layered on top of the ongoing action. For example, parents often made statements such as "It looks like the horse is running" or asked questions such as "Hear that galloping sound?"

In 29% of interactions, parents went beyond focusing children on relevant evidence to engaging children in discussions about the appropriate encoding of the evidence. Consider the following example of a girl and mother. As the videotape segment begins, we see the zoetrope already spinning very quickly in a counterclockwise direction. The previous visitor had spun it hard and then immediately walked away. The target child approaches and kneels to look through the slots. Because the zoetrope is turning counterclockwise, the horse appears to be running forward. Within 1 s her mother appears and looks over the top of the zoetrope before bending down to look through the slots. After about 10 s, the girl stands and grabs the zoetrope to stop it.

> Parent: "Now make it go this way [gestures as if spinning th zoetrope clockwise] and see what happens."
>
> Child and P spin zoetrope clockwise together and then look through the slots.
>
> C: "It's the same."

The girl makes an error. The zoetrope is now spinning clockwise and the horse appears to be running backwards. However, accurately judging the direction of running turned out to be difficult for children and sometimes even for adults. The animation of the horse running backwards at first appears a little unusual, but it is not immediately obvious why until one looks closely at the legs. The mother encourages the girl to explore further.

> P: "Is it running the same way?"
>
> C stops the zoetrope, pushes it in the opposite [counterclockwise] direction, and looks through the slot.

P sits down on the floor next to C.

C stops zoetrope and stands to look over the top at the still frames of animation.

C: "Oh it's facing that way [points to her right]. That's why."

P: "So if you turn it this way [counterclockwise gesture] which way is it running?"

C spins zoetrope slowly counterclockwise while looking over the top at the animation. She points to her right, which, given the orientation of the animated horse, corresponds to running forward. She then spins the zoetrope slowly in the opposite direction [clockwise] while still looking over the top.

C: "It's still going that way!" and points to her right.

C gets back down on her knees, looks through the slots, and spins counterclockwise.

P: "Now which way's it running, forward or backward?"

C points again to her right.

C: "That's forwards."

P: "Yep."

C stops zoetrope.

P: "Turn it the other way."

C turns the zoetrope in the opposite direction [clockwise].

C: "It's going that way." [points again to the right]

P: "Is it? (pause) Is it? (pause) Look at the way its legs are going."

C: "Ohhh! (excitedly) It's going back, back, backwards!"

Before the mother's finally encouraged the girl to encode how the legs moved, the girl appeared to steadfastly resist the notion that changes in direction of spin were associated with changes in direction of running. This was despite the fact that girl herself had earlier offered a potential reason why the direction of running might change with direction spin when she said: "Oh it's facing that way [points to her right]. That's why." Without the mother's repeated challenges, the girl may never have noticed that she incorrectly encoded a key piece of evidence.

Parents Helped Children Generate Evidence. We considered parent guidance on two levels: pointing children to one part of the evidence space and suggesting comparisons between at least two different parts of the evidence space. The most basic form of parent guidance was pointing children to one part of the evidence space by directly instructing them to use one of the four operators without embedding the suggestions in a specific comparison. For example, a target boy and his mother approached the zoetrope together while an older sister lingered at a nearby exhibit. The mother crouched down and put her hands on the zoetrope, preparing to spin it.

Parent: "I want to show you something. Are you ready to go?"

Child: "Yeah."

P: "Look, put your head down here [points to slots] and look through the holes. Ready?"

C crouches down.

Sister approaches and crouches down by C.

C leans forward, peering through the slots, until his nose is almost touching the zoetrope.

P: "Don't get your face that close!" [while gently guiding B's head back]

P: "Ready?"

C: "Uh huh."

P spins the zoetrope counterclockwise.

C and P watch through the slots.

Parents provided such basic guidance in 49% of interactions. As in this example, parents were most likely to tell children to look through the slots (39% of all parent–child interactions); followed by using the tabs (22%), and spinning the zoetrope (14%). We did not code a single instance of parents directly telling children to look over the top of the zoetrope.[4]

In 33% of interactions, parents went beyond pointing children to a single location in the evidence space to suggest a comparison between two kinds of evidence. An instance of this can be seen in the earlier example of the mother and girl exploring the direction of motion. As is suggested by the first line of the transcript, the girl's struggle with encoding evidence may have never occurred without the mother's initial suggestion that they spin the zoetrope the other way to "see what happens." Suggesting comparisons related to the direction of spin was most common (20% of parent–child interactions), followed by comparing sound patterns created by different tab configurations (10%), comparing the animation when seen through the slots vs. over the top (8%), and comparing how fast the horse appeared to be running when the zoetrope was spun at different speeds (2%).

Parents sometimes provided basic guidance and suggested comparisons in the same interaction. Overall, 57% of parent–child interactions included at least one instance where parents guided children's exploration of the evidence space.

Parents Explained. In 37% of interactions, parents provided an explanation, either causal, analogical, or principled. Explanations of local causal connections within the exhibit were most common, appearing in 31% of parent–child interactions.

Parent: "See you can make it gallop like this."

P starts putting up all the tabs.

P: "Because every time it goes through there [points to photoelectric switch] it pops, see?"

P rotates the zoetrope slowly so that one tab triggers the switch. Child begins raising tabs.

The next most common form of explanation (25% of interactions) was suggesting analogical connections between the zoetrope and related devices. The analogies were typically

[4] Here and elsewhere the sum of the breakdowns of specific kinds of talk can be greater than the overall percentage because parents could be coded as engaging in more than one specific kind of talk per interaction.

brief links made between the zoetrope and movies, television, or, as in the following example, cartoons:

> Child is crouched down looking through slots of spinning zoetrope.
>
> Parent crouches down next to B to look through slots.
>
> P spins zoetrope again.
>
> C: “Ohhhhh...”
>
> P: “Like, uh, that’s how they make cartoons.”

Finally, in 4% of interactions, parents introduced unobservable principles responsible for the illusion of motion. For example, a boy had been spinning and looking through the slots when his mother approached, helped to spin the zoetrope again, and then bent down to look through the slots. The boy looks up.

> Child: “Mama, it looks like it’s moving for real.”
>
> Parent: “Yeah.”
>
> P spins the zoetrope again.
>
> C looks again through the slots.
>
> C grabs zoetrope to stop it.
>
> C: “Why’s it look like that?”
>
> P: (pause) “Because your mind… your eye… sees each little picture and each one’s different from the other one [points to the animation frames], but your mind puts it all in a big row.”
>
> C: “It starts out like that [points to animation frames] and then it goes and goes.”
>
> C spins zoetrope and crouches down once more to look through the slots.

Note from this example that the mother explained because the boy asked why. To test whether parent explanations were in general prompted by children’s questions, we examined the 10-s leading up to each parent explanation to see whether children had asked a question or stated that they did not understand something about the zoetrope. This analysis revealed that explanations in response to questions were rare, accounting for only 11% of parent explanations. We also adopted a more liberal criterion of considering explanations to be requested if, at any point in the interaction prior to the first explanation, children asked any type of question on any topic. As expected, the liberal criterion increased the percentage of adult explanations following children’s questions, but only to 29%. Thus, most parent explanations appeared to be the result of the parent deciding to introduce an explanation on top of the ongoing activity.

DISCUSSION

This study was designed to provide a window into the everyday scientific thinking that occurs in parent–child interactions. Findings suggested that children engaged in shared scientific thinking with their parents had greater opportunity to learn than children engaged in scientific thinking with peers or by themselves. First, when engaging the exhibit with their parents, children's exploration of evidence was observed to be longer, broader, and more focussed on relevant comparisons than children who engaged the exhibit without their parents. Second, parents talked to children about identifying, generating, and interpreting evidence. Specifically, parents helped children select and encode relevant evidence in about half of the parent–child interactions. The majority of interactions included parent talk about how to generate new kinds of evidence or make direct comparisons between different kinds of evidence. Finally, in over one-third of interactions, parents assumed the role of explainer by casting children's experience in causal terms, connecting the experience to prior knowledge, or introducing abstract principles.

We begin by discussing these findings with respect to what they suggest for the two dimensions of children's scientific thinking that have dominated recent developmental studies: developments in evidence collection and developments in theory construction. First, consider the implications of these findings with respect to the question of how children develop strategies for collecting and interpreting evidence. Compared to adults, children's evidence collection is often described as being less systematic, less likely to include informative comparisons, and less likely to be exhaustive (e.g., Dunbar & Klahr, 1989; Kuhn et al., 1988; Schauble, 1996). Developments in evidence collection have typically been described as metacognitive advancements that enable children to deploy increasingly sophisticated experimentation strategies, to construct more accurate and complete encoding of incoming evidence, and to search for evidence that is inconsistent with their existing beliefs. The current findings suggest that parents may provide extensive support for each of these developments in everyday settings. The findings replicate those of Gleason & Schauble (2000), where an experimenter asked parents and fifth or sixth grade children to work together on a 45-min design task. We extend Gleason and Schauble's findings by showing that parents provide appropriate support for the evidence collection of younger children when families are engaged in spontaneous, rather than obligatory, collaboration.

Second, consider the implications of the current findings for children's construction of theories. Those who have focused on the content of children's developing scientific knowledge have in large part been interested in ontological organization and constraints, in part to account for the fact that even young children have surprising rich theories and are able to make adaptive decisions about assigning novel instances to appropriate categories (Wellman & Gelman, 1998). Our findings suggest that children do not always have to solve this categorization problem in isolation. The current findings suggest that parents sometimes provide constraints for theory building by highlighting the most relevant kinds of evidences from all possible evidences. These findings are consistent with prior work showing that parents sometimes provide guidance to children that is sufficient to provide useful constraints for the child's construction of explanations (Callanan, Shrager, & Moore, 1996; Gelman, et al., 1998; Shrager & Callanan, 1991). Even if one accepts the position that the development of children's theories is best described as a process that takes place "within the head" of the individual child, these findings suggest that parents may at least play a role in filtering and focusing the evidence that children notice and remember.

However, our findings also suggest that parents frequently went beyond constraining evidence to directly offering explanations that explicate causal structure, suggest analogical links, and describe general unobservable principles. Thus, much of the knowledge necessary to constrain children's theory construction may be available from spontaneous parent assistance. We have coined the term *explanatoids* to describe the kinds of brief, sketchy, and somewhat mundane explanations that parents introduce into everyday collaborative exploration. In contrast to the more elaborate and complete explanatory conversations that can occur in more reflective moments of everyday activity (e.g., Callanan & Oakes, 1992), explanatoids are brief explanatory prompts thrown into ongoing collaborative exploration or problem solving strategy. They are not sufficient to teach complete concepts or strategies. Instead, we think of them as "just-in-time" explanatory nuggets that are offered when relevant evidence is the focus of joint parent–child attention and that serve the function of providing children an on-line structure for parsing, storing, and making inferences about evidence as it is encountered (Crowley & Galco, 2001).

Is there evidence to suggest that this kind of parent explanation during collaborative parent–child activity makes a difference in terms of children's learning? The observational methods used by our study were designed to sample spontaneous moments of parent–child thinking and cannot provide direct evidence about the extent of children's learning. However, recent laboratory studies suggest that adult explanations can facilitate both children's problem solving and theory construction. When adults explain as they demonstrate new problem solving strategies, children are better able to transfer strategies to novel problems (Crowley & Siegler, 1999). When adults provide causal explanations as children construct family-resemblance categories from novel instances, children are more accurate in categorizing subsequent instances (Krascum & Andrews, 1998). There are also studies to suggest that if adults do not provide such explanations or at least prompt the child to produce their own explanation, it is unlikely that children will decide to do so on their own (Goncu & Rogoff, 1998; Siegler, 1995). Thus, available evidence from laboratory studies supports the possibility that the spontaneous parent explanation we observed could facilitate children's learning.

Before closing, we should note two limitations of the current study. First, as with any cognitive task, much of the variance we observed in exploration and conversation is likely to be attributed to the design and implementation of the particular exhibit we observed. We chose the zoetrope exhibit in part because it was consistent with exhibit principles that support family collaboration (Borun & Dristas, 1997; Crowley & Callanan, 1998) and in part because it characterized features of open-ended tasks that are often used in psychological research on scientific thinking (Klahr 2000). However, different tasks under different conditions would likely affect some of the patterns of our findings. Second, while the methodology of this study provides a high-resolution snapshot of a moment of family activity, it does not provide a broader look at how that moment fits into the overall museum visit or a deeper look at how that moment fits into the ongoing development of children's scientific literacy across contexts and time. The findings of this study are best seen as a single empirical step toward the larger goal of constructing a complete account of the development of scientific literacy that integrates what we know about scientific thinking from a cognitive perspective and what we know from studies of out-of-school learning contexts (e.g., Falk & Dierking, 2000).

Although we have so far emphasized family visits to a museum as an example of a broader class of parent–child activity, we are deeply interested in the museum itself as a location for family science education. Converging evidence from studies of scientific thinking in everyday, instructional, and professional settings describe a developmental corridor that stretches from everyday learning in contexts such as museums, through formal science instruction in classrooms, to the daily activities of practicing scientists (Crowley, Schunn, & Okada, 2001). The current findings serve as a reminder that parents provide guidance, coaching, and encouragement as children move through this corridor. Parents who involve children in informal science activities provide an opportunity for children to learn factual scientific information and to practice scientific reasoning, but they also provide an opportunity for children to participate in a culture of learning about science. In terms of future classroom success or later choices about science as a career, the most important outcome of everyday parent–child scientific thinking may be that children develop an early interest in science, value science as a cultural practice, and form an identity as someone who is competent in science.

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