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Everyday Activity and the Development of Scientific Thinking

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Years before encountering their first formal science lessons in elementary school, children may already be practicing scientific thinking on a weekly, if not daily, basis. In one recent survey, parents reported that their kindergartners engaged, on average, in more than 300 informal science education activities per year—watching science television shows, reading science-oriented books, and visiting museums and zoos (Korpan, Bisanz, Bisanz, Boehme & Lynch, 1997). This strikes us as a lot, but it is likely to pale in comparison to what young children may experience five years from now. Encouraged by findings suggesting that children's out-of-school activities and learning environments are linked to motivation and success in the classroom (e.g., Gottfried, Fleming, & Gottfried, 1998), developers continue to expand the number of science-oriented museums, internet sites, books, and television shows specifically designed for young children. But what constitutes effective learning environments? What are the knowledge bases, processes, and practices that good informal science education should seek to develop?

It seems natural that at this moment, psychologists interested in cognitive development would step to the fore with their research-based knowledge of how children learn to think scientifically to work as partners with developers to produce effective informal learning environments. But, as many have noted with respect to classrooms and formal education, it is almost never the case that basic learning research can be translated immediately into effective practice. The complexity, extended time-scale, and socially-embedded nature of *in vivo* learning and development are not just annoyances to be controlled by an experimenter; they are fundamental, irreducible characteristics of how learning actually occurs (Brown, 1992).

Laboratory studies of children's learning have produced an important body of findings about the ways that children develop scientific thinking. However, those findings will remain inert and untapped unless there is also research that situates mechanisms identified in laboratory studies within the patterns and practices that actually occur as children develop everyday scientific literacy in the real world (see Stokes, 1997, for discussion about fruitful ways to reconsider issues of basic vs. applied research).

In this chapter, we overview a line of research designed to extend prior laboratory-based research on children's scientific thinking to the everyday contexts where it actually occurs. We describe analyses of naturally-occurring parent-child interactions as families use interactive science exhibits in children's museums. We describe how parent participation extends children's exploration of an exhibit and describe how parents sometimes offered brief explanations to frame the ongoing activity. We close by reflecting on what our findings suggest about everyday parent explanation and the development of children's scientific thinking.

Developing Scientific Thinking in Everyday Settings

In this chapter, we describe a line of work that has grown from the simple idea of looking to the cognitive ecology of children's everyday thinking for guidance on how to think about the development of scientific thinking. Developmental psychologists interested in cognitive development have a long history of research inspired by observations of children's thinking in everyday contexts. The foremost example is probably Jean Piaget, whose accounts of his own children's exploits still provide a conceptual touchstone for much of modern cognitive developmental research. It remains commonplace to hear researchers weave anecdotes about their own children into conference presentations and colloquia (Gauvain, 1997), and it is not unusual for new lines of successful experimental work to grow out of chance observations of children that, for one reason or another, strike a researcher as inconsistent with some aspect of a prevailing theory (Okada, this volume).

Yet, the vast majority of studies of children's cognitive development take place in the context of laboratory studies where individual children work alone to complete clever, but contrived, laboratory tasks. As Dunbar points out in this volume, *in vitro* studies are a powerful, albeit limited, scientific tool. Although they provide control, precision, and convenience, they provide no built-in reality check. There is always the possibility that, as researchers extend, elaborate, and perfect programmatic *in vitro* paradigms, they will develop increasingly specified, nuanced, and replicable answers to questions that may not be the best reflection of actual developmental processes.

As in the field of cognitive development at large, most of what is known about the development of scientific thinking is based on evidence from laboratory studies. The studies have been of two kinds. First, some studies have focused on children's scientific reasoning processes, including their abilities to design controlled experiments, make valid inferences, and generate new hypotheses. Compared to adults or adolescents, children are often observed to be less systematic when considering evidence, less likely to conduct informative comparisons, and more likely to see all of the relevant evidence when in engaged in self-directed scientific thinking (e.g., Schauble, 1996, Dunbar & Klahr, 1989; Kuhn, Amsel, & O'Loughlin, 1988). Developments in scientific reasoning are often described as general improvements in individual metacognitive abilities 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 (e.g., Kuhn, 1989).

Other studies have focused on the content and structure of children's concepts, mental models, and naïve theories in scientific domains such as biology, physics, and psychology. For example, in the absence of any direct instruction, children appear to develop mental models of the shape of the earth (Vosniadou & Brewer, 1992) and theories about what fundamentally distinguishes biological and physical entities (e.g., Wellman & Gelman, 1998). In addition to describing age-related differences in concepts, mental models, and theories, research focused on the content of children's scientific knowledge has sometimes explored how the structure of knowledge constrains categorization of new instances. For example, Chi and Koeske (1983) described a young dinosaur expert who, through repeated reading of dinosaur books with his mother, had developed a well-organized semantic network of dinosaur knowledge that enabled him to categorize and recall novel dinosaurs more accurately when they were related in meaningful ways to his prior knowledge.

Although sometimes focusing on the process and sometimes focusing on the product of scientific thinking, extant work emphasizes internal cognitive mechanisms such as metacognition, knowledge-based constraints, or theory revision to explain learning and development. These are appropriate mechanisms given the situtation of an individual child in a laboratory setting. It is probably true that, when working alone on a novel task, younger children are less systematic than older children due to less sophisticated metacognitive skill. It is probably also true that the surprisingly advanced performance of young children on certain categorization tasks suggests that they hold naïve theories that constrain how they interpret and organize new evidence.

But, are the mechanisms that appear to be central in laboratory studies the same mechanisms that appear to be central in everyday settings? It is logically possible that developing scientific thinking is best thought of as an individual struggle where breakthroughs occur as children develop internal metacognitive skills or as children tinker, gradually or suddenly, with the contents and organizations of their everyday scientific theories. But we think an alternative is at least worth testing: That parents actively involve their children in activities and conversations that directly shape children's early scientific thinking. After all, the kinds of activities where young children are most likely to encounter science are activities often embedded in the context of parent-child interaction—activities such as parents reading picture books to young children or families visiting a museum or zoo together on the weekend. What does this shared scientific thinking look like?

A Location for Research on Everyday Scientific Thinking

The first step in exploring the characteristics of children's everyday scientific thinking was to choose a location to observe it. We chose to focus on naturally occurring family activity at interactive science exhibits in museums. Similar to the computer microworlds that have often been used in laboratory studies of children's scientific thinking, interactive science exhibits use environments where children can generate evidence, interpret evidence, and build theories relevant to particular science or technology content. However, exhibits are also authentic artifacts used by families in the context of recreation and education independent of our research activities. Thus, interactive science exhibits seemed to be a fruitful location to explore whether and how findings from extant scientific thinking research are reflected in everyday activity.

As an example of an interactive exhibit, consider the zoetrope (Figure 1). This is a simple animation device with an animation strip on the inside of a drum that visitors can spin. If they spin and look through the slots, the exhibit 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).

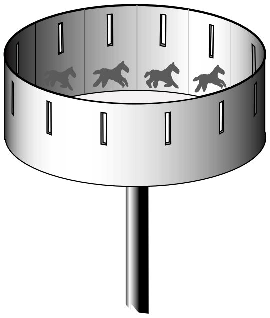

Figure 1. A zoetrope affords simple exploration, observation, and explanation.

The zoetrope affords simple manipulations and straightforward connections to animation—a topic with which children and their parents are likely to be familiar. Unlike some interactive science exhibits, it does not produce amazing, unexpected, and unique outcomes that surprise and astound visitors. Furthermore, it is easy for even toddlers to use the zoetrope without assistance. If a child is about 30 inches tall and can stand on her own, she is capable of spinning the cylinder and observing the animation through the slots. Thus, the zoetrope is a good example of everyday scientific thinking where children could explore and where parents could chose whether or not they will shape the path of exploration, help children to place the experience in a broader context, or step back and allow the child to do it by themselves.

The particular kind of scientific thinking that is most common at interactive science exhibits like the zoetrope is an informal kind of evidence collection and evaluation. Most children do not come to interactive science exhibits with well-organized plans to conduct systematic investigations to test specific hypotheses. Instead, they adopt an informal mode of exploration where the initial goal is often to poke around and see whether the exhibit does anything interesting. If something sufficiently intriguing occurs, children may decide to pursue it further, perhaps experimenting with different conditions that are necessary to produce the outcome or that modify it in an interesting way.

By normative definitions of scientific thinking, this may not sound much like scientific thinking. However, as many of the chapters in this volume note, including Simon's, Okada's, Dunbar's, Chinn's and Malhoutra's, and Tweney's, the actual cognitive processes of scientific thinking only sometimes resemble normative prescriptions. We think it is common for children in everyday settings to conduct informal, recreational exploration of their environment. We agree with Simon's argument (this volume), that seeking out evidence, noticing interesting patterns, and making inferences about evidence are natural features of the cognitive ecology of childhood. Such exploration requires no formal hypotheses or formal references to existing theories. Children are simply curious, attentive to novelty, and trying to make sense of their world as best as they can.

Characterizing the Exploration of Solo Children and Children with their Parents

What does everyday scientific thinking look like at interactive science exhibits? We present two examples of children using a zoetrope: One uses the exhibit solo, while the other uses it with her mother.

Before we describe these examples, we should pause to say a word about methodology. Both of these interactions, and all of the subsequent work we will present in this chapter, were collected with the same methodology, designed to be a low-impact, unobtrusive means to collect spontaneous use of exhibits during normal family museum visits. Before each day of data collection, video cameras were set up at target exhibits throughout the museum and wireless microphones were integrated into the exhibits to provide high resolution audio recording. Signs informing visitors of our research activities were hung at the museum entrance and at each exhibit being filmed. Researchers greeted families entering the museum, explained that we were videotaping as part of a research project, and asked families for written consent to participate. Most families (typically greater than 90%) agreed to participate. Children in consenting families were given large stickers identifying them as participants; ages of the children were determined by distinct stickers. If, in the normal course of their visit, children with stickers chose to engage one of the target exhibits, the camera operator turned on the camera for the length of the engagement.

	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.

Now we return to our comparison of the children who used the zoetrope with and without their parents. To describe their exploration of the zoetrope, we adopted the convention of considering evidence collection as movement through a search space (e.g., Klahr & Dunbar, 1988). As shown in Figure 2, the search space for the zoetrope is a simple factorial space defined by whether the zoetrope was spinning or still and whether the child was looking at the animation through the slots or from over the top of the cylinder. In each of the four spaces, children perceive the animation differently. By collecting data in different parts of the space children could accumulate evidence to support inferences about how and why the zoetrope worked.

First, consider the exploration of a 5 year-old girl who was without her parents as she engaged a zoetrope at the Pittsburgh Children's Museum. As Figure 3 suggests, the solo girl's exploration was shallow and incomplete. She spun the zoetrope several times but never observed the true animation effect by looking through the slots. She only observed the animation by looking over the top of the zoetrope—a view that produces either a series of moving but separate frames or a blur, depending on how fast the zoetrope is spinning. As she spun the zoetrope, she often looked away from the exhibit. Midway through the engagement, she looked under the zoetrope—perhaps an attempt to find out if there was anything else to do or see at this exhibit. However, there was nothing to see under the zoetrope and the girl quickly lost interest, stopped the spinning zoetrope, and left.

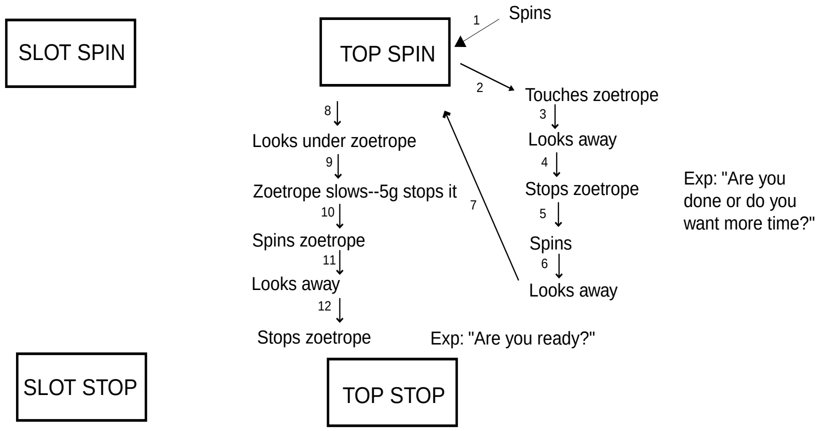

Figure 3. Tracing the activity of a 5 year old girl who explored the zoetrope by herself. The four categories of evidence that children could encounter are included as boxes in the center of the chart. Actions are transcribed as text connected with numbered arrows indicating the order in which they occurred. When an arrow enters one of the four cells of the exploration space, it indicates that the child was seeing that category of evidence at that point in the engagement.

Contrast the shallow and incomplete search of the solo girl with that of a 6 year old girl who engaged the zoetrope with her mother (Figure 4). While the solo girl had entered only one cell of the evidence space, the girl with her mother entered three of the four cells and spent the most time in the critical SlotSpin cell. The interaction began with the girl looking at the animation through the slots and calling her mother's attention to it: "Mom, look at this!" The mother began almost at once to guide the girl's exploration. She suggests an informal experiment, telling her daughter to "do it as fast as [she] can and see what happens." The girl takes up the suggestion and notes the outcome: "Yeah, they are running really fast. The mother then begins a brief episode of explanation. She starts with a question: "Do you have any idea how this works?" The girl does not answer the question, but stops the zoetrope from spinning and looks first through the slots and then over the top.

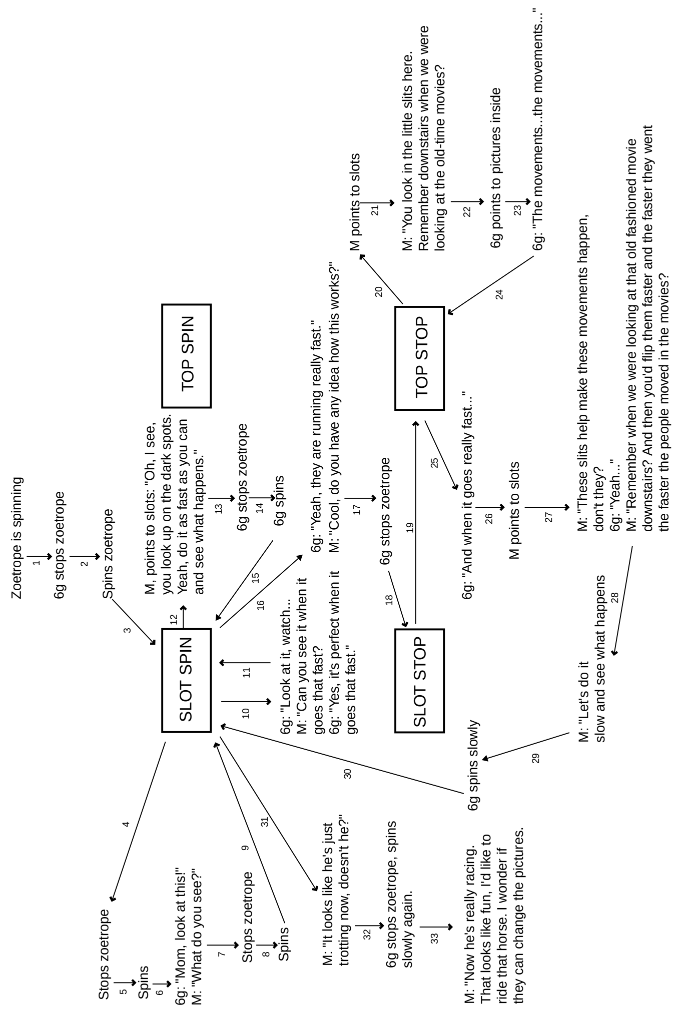

Figure 4. Tracing the activity of a six-year-old girl (6g) and her mother (M) as they explore the zoetrope.

The mother follows up the question by pointing to the slots and then asking the girl if she remembers the "old-time" movies that they saw downstairs. This is a reference to a faux-antique flip card device that happened to be on the lower level of the museum as part of a traveling exhibition. The mother also explicitly established a causal role for the slots—"These slits help make these movements happen, don't they?"—although she did not extend to a more complete explanation of why the slits help to make the movements happen. Next, the mother returned to the old-fashioned movie, connecting the speed of spinning experiment with a similar comparison they had they apparently conducted earlier at the old-fashioned movie.

The engagement wraps up with the mother suggesting: "Let's do it slow and see what happens." The girl complies and the mother volunteers an interpretation of the outcome: "It looks like he's just trotting now, doesn't he?" As the engagement comes to a close, the mother is making casual conversation, mentioning that it might be fun to ride the horse and wondering whether it is possible to change the pictures inside the zoetrope.

There are two things to note about these two examples. First, compared to the girl who engaged the zoetrope alone, the girl who engaged it with her mother spent more time at the zoetrope, entered more cells in the evidence space, re-entered cells more often, conducted pair-wise comparisons between cells in the evidence space, and spent more time in the critical SlotSpin cell. Second, the girl who used the zoetrope with her mother participated in an ongoing conversation about generating, interpreting, and explaining evidence as she explored the zoetrope. We know nothing about the inner dialog of the girl who used the zoetrope by herself, and it is possible that she may have made have engaged in some similar form of reflective commentary and self-explanation. However, her cursory exploration seems unlikely to have provided her with sufficient evidence to support much in the way of reflection.

A Broader Study of Shared Scientific Thinking

How general are the characteristics suggested by these two examples? We examined exploration and conversation among families who, in the normal course of a museum visit, decided to use a zoetrope at the San Jose Children's Discovery Museum (Crowley, et al., in press). We compared the activity of 49 families where parents and children happen to use the exhibit together, to the activity of 20 families where children happen to use the zoetrope by themselves while their parents were occupied elsewhere in the museum.

Exploration

Consistent with the two examples we already presented, findings suggested that children's search of the zoetrope was extended and more focused when they used the exhibit with their parents. Figure 5 illustrates differences in the evidence encountered by children who used the zoetrope either with their parents or by themselves.

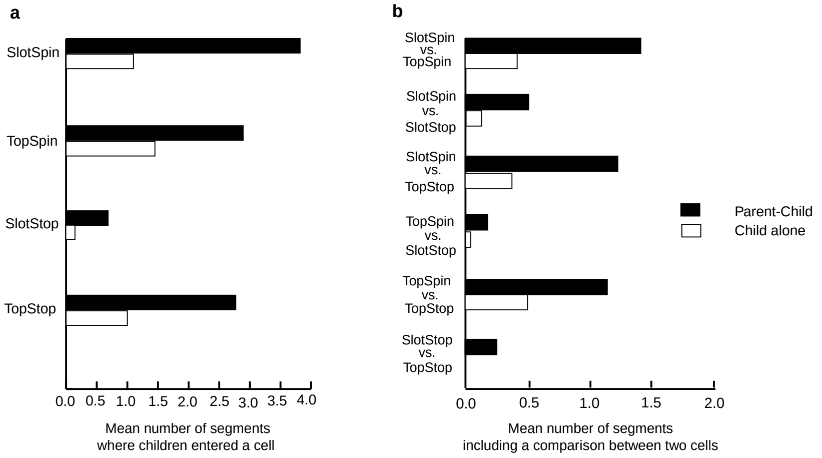

Figure 5. Children s exposure to evidence while using the zoetrope. a) Children using the exhibit with their parents encountered each kind of evidence more often than children by themselves, and b) were also more likely to make direct comparisons between different kinds of evidence.

To estimate the amount of exposure children had to each kind of evidence, we divided each interaction into 10 second segments and coded whether children had seen each category of evidence within each 10 second segment. As shown in Figure 5a, children who engaged the zoetrope with their parents visited each cell of the exploration space more often than children who were alone. Furthermore, notice that the most common cell visited by children with parents was the critical SlotSpin cell—the cell in the evidence space where children can observe the illusion of motion. In contrast, children alone spent less time, both in absolute and relative terms, viewing the animation. Children alone spent the most time in the TopSpin cell and equal amounts of time in the TopStop and SlotSpin cells.

In addition to counting how often children saw each kind of evidence, we also tracked how many paired comparisons children made, defined as children entering two cells within the same 10-second segment. 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 to perceive a spinning series of non-animated 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.

As shown in Figure 5b, children with parents were more likely than children alone to engage in each of the six possible paired comparisons. Consistent with the finding that children with their parents spent the most time in the SlotSpin cell, the most common kind of comparison for children with parents was between SlotSpin and TopSpin evidence. In contrast, the most common comparison for children alone was between TopSpin and TopStop evidence. It is worth noting that it was not necessarily the case that children with their parents would make more comparisons than children alone just because the earlier analysis revealed that they spent more time in each cell of the evidence space. If children with their parents had engaged in a serial, non-backtracking search of the whole evidence space, of if they had searched until they found the critical SlotSpin cell and then looked no further, they would have performed fairly few comparisons regardless of how much time they spent using the zoetrope. However, findings suggest that children using the zoetrope with their parents continued to collect different types of evidence and to make comparisons between them, even after they had achieved the initial effect of seeing the animation.

Thus, consistent with the two examples we presented above, children with parents explored the zoetrope more deeply than other children and were most likely to focus on the most interesting cell in the evidence space. Furthermore, their exploration included high levels of direct comparison between different cells in the evidence space, particularly between SlotSpin vs. the other kinds of evidence. In contrast, solo children appeared to distribute their attention more equally throughout the space.

Conversation

We turn next to consideration of the talk between parents and children who used the zoetrope together. Return for a moment to the conversation between the mother and daughter depicted in Figure 4. The pair keep up a fairly constant level of talk throughout the interaction and both mother and daughter participate in the conversation. However, the mother is responsible for most of the suggestions for how they might explore, for most the commentary on the evidence as it is encountered, and for all of the explanatory talk about the slots and the relation of the zoetrope to the old-fashioned movie exhibit downstairs.

The parent-child conversation in Figure 4 is in some ways typical of the conversations one can observe at interactive science exhibits. It is often the case that parents and children talk when they are engaged in collaborative activity at exhibits. In the broader study of family exploration of the zoetrope, we recorded talk in 92% of families where parents and children used the zoetrope together. Although it was almost always the case that both parents and children contributed something to the conversations, most of the talk was carried out by parents. Parents were twice as likely as children to talk about how to generate evidence—defined as talk about how to manipulate the zoetrope, such as, “Spin it the other way” or “Look through those slots.” Parents were seven times as likely as children to describe evidence as it was being encountered—defined as talk about observable outcomes that did not established causal or analogical connections such as “It looks like he’s galloping” or “Is he running backwards?”

Finally, parents were about five times more likely than children to explain. We coded parent talk to be explanatory if they talked to their children about causal relations, noted analogies between the zoetrope and related devices, or made general statements of the scientific principles underlying the exhibit. Causal explanations included talk about causal links within the local context, such as, “Look, if we slow it down, the pony runs really slow. And if you make it go fast, the pony goes really fast.” Analogies included talk that made a connection between the exhibit and prior knowledge or prior experience such as, “Remember when we made the little comic book on the bottom of the page and you flip the whole notebook and it made it look like it was a moving cartoon? …I think this is the same kind of thing.” Principles included talk about underlying unobservable causal principles; for example: “They wanted to take a look at how pictures move, see how they drew the pictures, and they’re all different, they're all in different positions, they move them … and if you look, look down here, you see?"

While reflecting some aspects of the average conversation at the zoetrope, the conversation depicted in Figure 4 is atypical in its completeness. While the mother in our example talked about how to generate, interpret, and explain evidence, less than half of the parents from the broader study provided each kind of assistance. Parents talked about how to generate evidence in 49% of interactions; talked about how to interpret evidence in 47% of interactions; and offered explanations in 37% of interactions.

Summary

We have described how parent participation shapes the path of children's naturally-occurring scientific thinking at one interactive science exhibit. When parents were present, children exploring the zoetrope saw more unique kinds of evidence, spent more time collecting the most informative kind of evidence, and were more likely to make paired comparisons between different kinds of evidence. Even if the development of scientific thinking is best explained by mechanisms "inside the head" of an individual child, our findings suggest that parents play an important role in enriching the evidentiary record on which individual children could make inferences, generate explanations, and construct new theories.

However, we also observed that parents often talked to their children about evidence while families used the zoetrope. Parents spontaneously provided assistance about how to generate new kinds of evidence by manipulating the zoetrope. They provided assistance about how to encode evidence and volunteered interpretations of evidence. Parents also provided explanation about causal connections within the experience, ways that the experience related to other experiences, and ways that the experience related to more general principles.

Explanatoids

What guidance might these findings provide for current accounts of the development of scientific thinking? We had made the argument earlier that the dominance of laboratory studies raises the question of whether current developmental accounts accurately reflect contexts where children think scientifically everyday. Our findings suggest that they may not.

In particular, current accounts of the development of scientific thinking may have underestimated the level of spontaneous parent assistance available to children in everyday environments. Studies of children's scientific reasoning have focused on young children's lack of systematicity during evidence collection. Studies of 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 surprisingly rich theories and are able to make adaptive decisions about assigning novel instances to appropriate categories. Our findings suggest that children may not have to solve problems of evidence collection and theory construction by themselves. We observed parents providing guidance in collecting and annotating evidence and parents offering explanations sufficient to facilitate at least some simple kinds of theory construction.

We think the most interesting insight might involve the finding that parents sometimes explain to their children while engaged in scientific thinking. Explanations are a privileged category of scientific discourse. At its core, science is a way of making sense of the world. It is a way of building up new theories to explain existing evidence, and a way of seeking out new evidence to revise existing theories. Current national standards for science education and current reforms in classroom science instruction emphasize explanation. Standards for science education proposed by the American Association for the Advancement of Science and the National Research Council advocate going beyond traditional science instruction to focus on facilitating the development of scientific "habits of the mind." These habits refer to general scientific reasoning skills, including coordinating evidence and logic in constructing and evaluating scientific explanations. In response to such guidelines, current science education reforms advocate hands-on classroom activities where students are actively involved in collaborating with classmates and teachers in explanatory activities such as forming hypotheses, interpreting empirical findings, and revising theories to account for new evidence (e.g., Lehrer, Schauble, & Petrosino, this volume).

Recent cognitive science research focused on the reasoning of practicing scientists reveals that effective explanation building between collaborators is often the source of scientific breakthroughs. In a multi-year cognitive ethnography of four molecular biology laboratories, Dunbar described the essential role of collaborative explanation in terms of scientists integrating findings, forming analogies to well-understood systems, and opening up new lines of inquiry (Dunbar, 1995). The labs that made important breakthroughs during the course of Dunbar's study were those that were best at constructing shared explanations during lab meetings. Consistent with Dunbar's findings, cognitive psychology studies of adults working on simulated science problems typically find that explanations are key mechanisms in creating and extending useful science learning (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Okada & Simon, 1997).

The unobtrusive observational methods of this study were necessary to capture natural moments of parent-child interaction. It is important to note that the findings we have presented in this chapter are observational and do not yet support causal conclusions about the effects of parent explanations on children's scientific thinking. 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). If adults do not provide such explanations or at least prompt the child to self-explain, it is unlikely that children will decide to do so on their own (Göncü & Rogoff, 1998; Siegler, 1996). Thus, available evidence from laboratory studies supports the possibility that the spontaneous parent explanation we observed could facilitate children's learning.

The finding that about one half of parent-child interactions at the zoetrope included an explanation struck us as a rather high level of explanation, given that previous studies had suggested that parents rarely explain in everyday settings. For example, Gelman et al.'s (1998) study of parents and children reading storybooks detected fairly few parent explanations. Perhaps the lower level of explanations relates to the fact that they studied reading. Reading with children is an activity primarily carried through language and pictures, primarily directed by the parent, and that does not involve extensive non-verbal explanation, manipulation, or creation. Although it may be ideal for studying certain categorization issues, book reading is not representative of a broad range of everyday activities where language may serve as a secondary layer to direct, encode, and connect non-verbal activity. Our research has focused on activity in a children's museum; however, the essential properties of museum activity characterize much of the everyday parent-child activity that goes on as children construct buildings out of blocks, help their parents cook, mix watercolors, garden, or figure out how a new toy or computer program works.

Similarly, Callanan and Oakes (1992) asked parents to keep a diary of children's questions and to note how they responded to the question. Parents reported an average of six explanatory discussions over the 2 week period; a number that seems somewhat low compared to the current finding that about one in four of the brief parent-child interactions in the museum included at least one form of explanation. However, there are two important differences in diary methodology and the methodology we have adopted. First, because parents were asked to keep track of children's questions, the study only revealed parent explanations that were responses to questions. Most of the explanations we observed in museums were offered by parents rather than requested by children. Second, in the diary study, parents needed to record conversations with their child off-line—sometimes hours after the actual conversation occurred. Thus, the diary methodology only detects conversations that are memorable and, from the parent's point of view, interesting enough to be reported to the researcher. In contrast, most of the explanations we have observed in our studies are no more than a few words uttered at an appropriate moment during the ongoing activity. Compared to the conversations reported in Callanan and Oakes (1992), the explanations we have observed seem brief, sketchy, and somewhat mundane. They were perhaps not the kinds of clever parent-child exchanges that a parent chooses to relate to grandparents, friends, colleagues, or, for that matter, developmental researchers.

We have coined the term "explanatoids" to characterize the simple, incomplete, and mundane explanatory talk that parents provide as they engage in collaborative everyday activity with their children. We hypothesize that explanatoids may have a broad impact on the development of children's scientific thinking. The family interactions we analyze here are sampled moments from a larger pattern of interaction that is woven throughout many different kinds of activities in which families engage. We do not conceptualize the most general kind of parent guidance as extended explanatory dialog that serves to catalyze, perhaps in a blinding flash of insight, the creation of a complete explanation that leads to large scale re-organization of a child's knowledge. Although such events may certainly occur, the more common kind of parent explanation is probably the kind we describe here. Although brief and incomplete, explanatoids are well-targeted to a moment of activity. Following from the idea of "active language" first suggested by Shrager and Callanan (1991), we hypothesize that explanatoids are powerful because they are offered when relevant evidence is the focus of joint parent-child attention and thus they serve the function of providing children an on-line structure for parsing, storing, and making inferences about evidence as it is encountered.

It is undoubtedly the case that parents sometimes produce explanations that are misleading or just plain wrong. This might happen because parents do not actually know the correct answer, because they do not think that children are ready to understand the correct explanation, or because, even if they know the correct answer, parents have difficulty constructing a good explanation on the spot. This could also happen if parents do not believe that correct explanations are necessarily the point of interacting with children in a museum. For example, in a recent study we asked families to look through some fossils together and talk about them. One mother encouraged her daughter to be creative rather than accurate. She asked her: "What do you think this one is?" while pointing to a velociraptor claw. The child put the claw on top of her head and said, "It's a horn!" The mother laughed and said, "Yes! It's a horn."

In the long run we do not think that it is much of a problem that parents are wrong. First, any single moment of explanation seems unlikely to have much of an impact given the thousands of explanatoids that parents probably pepper their children with in the course of a normal year. In both conceptual development and problem solving, one-trial learning is rare—it is more often the case that new knowledge is forgotten and re-discovered several times before it becomes an established part of a child's theory or a child's collection of problem-solving strategies (e.g., Siegler & Crowley, 1991). We doubt that encouraging parents to explain in museums or elsewhere will lead to great misconceptions that will have to be later unlearned in science classrooms.

Second, it seems to us much more likely that parents will get closer to a good explanation than children will on their own. The kinds of statements we observed at the zoetrope were not very advanced—the most complete explanation we observed about principles of the exhibit fell far short of what would be an acceptable explanation in a science class or a textbook. This observation is at the heart of what we believe explanatoids are. Explanatoids provide simple but helpful prompts which shape children's theory building and strategy development; they are not fully formed explanations that are to be internalized as a completed product. And, simple but helpful prompts are not that difficult for adults to generate correctly. In a recent study we asked adults to generate conceptual, analogical, and principled explanations for the zoetrope: Over 75% were able to produce what we considered to be accurate examples of all three.

Conclusions

More generally, we think the most important implication of our findings is not that parents are providing declarative content for their children's theories, but that parents are modeling a specific kind of meaning-making for their children. Scientific thinking, like the specific thinking that characterizes other disciplines, might be considered a specific kind of causal reasoning with its own rules about what constitutes acceptable theory, evidence, and argument. When we observed parents talking to children about explanations, we saw them not only shaping the interpretations possible for their child at that moment, but also perhaps scaffolding their children's transitions from general causal thinkers to early scientific thinkers. A parent who explains an interactive exhibit to their children may increase the likelihood that the children understands the exhibit and may also demonstrate that constructing a causal, analogical, or principled explanation is an appropriate activity when one is manipulating a device either to engineer an outcome or just to see what happens.

In many ways, this argument echoes those that have been made about the development of literacy. Findings suggests that early out-of-school parent-child activities such as story book reading are linked to reading and writing outcomes once children enter school. Among the causal mechanisms proposed to explain this link is that parents who involve children in out-of-school literacy activities not only support the direct development of literacy skills but also instill in children the value that practicing the habits of literacy is an important priority throughout life.

It seems likely that a related scenario exists in the case of scientific literacy: Parents who involve children in informal science activities not only provide an opportunity for children to learn factual scientific information, but also provide opportunities for children to engage in scientific reasoning, to develop an interest in learning more about science, and to develop a sense that practicing the habits of scientific thinking is an important priority. Similarly, children are learning a lot about science years before they are taught official science curricula in classrooms. Whether children are visiting museums, watching television shows like "Bill Nye the Science Guy," surfing the Web, or using a chemistry set, parents are often available to children to act as guides and interpreters. 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 not be the content children acquire, but the interest, habits, and identity they form as someone who is competent in scientific thinking.

Acknowledgements

Supported by a grant from the National Science Foundation (ESI-9815021). Special thanks to our museum partners, including Sally Osberg, Jenni Martin, and Tom Nielsen at the Children's Discovery Museum of San Jose, and Jane Werner and Chris Siefert at the Pittsburgh Children's Museum.

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