Explanatory Conversations and Young Children's Developing Scientific Literacy

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When designing programs for science learning, it is important to consider that children's experiences with science begin years before they encounter science in the classroom. Children's developing understanding of science begins in their everyday activities and conversations about the natural and technical world. Children develop "scientific literacy" as they begin to learn the language of science (e.g., concepts such as "gravity" or "metamorphosis"), the kinds of causal explanations that are used in scientific theories (e.g., the day-night cycle results from the rotation of the earth), and the kinds of procedures that are used to answer scientific questions (e.g., testing hypotheses, controlling variables). Laboratory studies of children's scientific understanding have uncovered crucial information about the cognitive processes involved in learning scientific topics (Carey, 1985; Chi, Slotta, & de Leeuw, 1994; Rosengren, Gelman, Kalish, & McCormick, 1995; Williams, 1985; Simon, 1985).
1991; Vosniadou & Brewer, 1992) and scientific reasoning strategies (Schauble, 1990; Klahr, Fay, & Dunbar, 1993). These studies provide the kind of controlled manipulation of variables that allow precise inferences about how children reason on certain tasks. What these laboratory studies cannot provide, however, is an understanding of the natural contexts within which scientific literacy emerges. Because aspects of scientific thinking seem to vary depending on experience and cultural background (Kuhn, 1996; Samarapungavan, Vosniadou, & Brewer, 1996), there is reason to believe that socialization may play an important role in its development. In this chapter, we consider everyday conversations with family members as a context in which young children begin to develop scientific literacy well before they enter school.

In particular, we focus on a discourse style that we call "explanatory conversation." As illustrated in the example that begins this chapter, these conversations include "why" questions and/or causal explanations. Many researchers have noted the sense of wonder in young children’s "why" questions about aspects of themselves and of the world around them (see Chukovsky, 1963; Piaget, 1974). As Simon suggests elsewhere in this volume, children’s questions represent just the kind of curiosity that is fundamental to initiating the process of scientific discovery. Parents also offer causal explanations to their children for how things work and why things happen, sometimes in answer to children’s questions and other times spontaneously (Callanan & Oakes, 1992; Crowley & Callanan, 1998; Callanan, Shragger, & Moore, 1995). These questions and explanations are components of the “explanatory conversations” that we consider in this chapter as social contexts within which children may be formulating and revising their understanding of scientific concepts.

Investigations of children’s conversations about science differ from experimental work in important ways and provide a different sort of data that is equally crucial to a precise understanding of human scientific reasoning. If we understand how young children experience scientific concepts and explanations as they arise in their everyday lives, we will be better able to assess the relative importance of individual cognitive processes and social experiences in children’s developing understanding of science. In this chapter we will discuss research exploring two main issues: (1) how children’s curiosity leads them to ask causal questions about scientific phenomena; and (2) how parents, in everyday conversations, guide children in interpreting scientific information and model ways of thinking about scientific processes. Along the way we will address questions about cultural differences in the ways that children learn to think about science, and discuss ways to assess the impact of explanatory conversations for children’s developing understanding of science. Finally, we will consider some theoretical ideas about how to integrate this type of research with the more traditional ways of studying scientific reasoning and ideas.

The study of explanatory conversations is motivated by several current approaches to the study of cognitive development, in particular, the “theory theory” approach, with its focus on the individual child, and the sociocultural approach, with its focus on the child in social context. The "theory theory" approach, presented by Gopnik and Meltzoff (1997) and Wellman and Gelman (1998) among others, focuses on how children’s naive theories of important domains change across development. Gopnik (1998) argues that seeking causes and explanations is a basic and universal component of human cognition. Recent sociocultural views, in contrast, have emphasized the social context of cognitive development (Rogoff, 1990; Rogoff, 1998; Tharp & Gallimore, 1988) and called for a shift from the focus on what children know to a focus on how children come to know within activity settings of their everyday lives. We will argue that the social context of explanatory conversations may be an important arena for children’s thinking about science. Within these conversations children and their conversational partners are creating the very settings in which children learn about the issues that are puzzling and interesting to them. We suggest that as a result of these conversations, children may develop and revise their “theories” about scientific (and social) domains. Parents’ participation in these causal conversations may provide children with information not only about science content, but also about whether asking these sorts of questions is valued in the community, and about how to begin to find answers. Rogoff, Mistry, Gönül, and Mosier (1993) suggest that explanatory conversation is a discourse style that is not necessarily shared across cultural groups. In their study, for example, Salt Lake City mothers were about twice as likely to explain the workings of a toy to their toddlers as were Mayan Guatemalan mothers. It is clearly essential to explore what explanatory conversations look like across different families, communities, and cultures.

The study of causal conversations in everyday situations, then, is a window on children’s thinking as well as on social contexts of learning. One challenge in this research, however, is that it is difficult to capture the moments of inquiry and discovery just as they are happening. Evidence suggests that explanatory conversations are likely to happen in the midst of everyday family activities, such as driving in the car or trying to cook a family dinner (Callanan & Oakes, 1992; Eisenberg, 1991), making it diffi-
cult for us as researchers to be in the right place at the right time. This also may mean that explanatory conversations are likely to occur outside of the settings where much of the research on parental input has taken place, largely experimenter-initiated tasks, free play, and book reading. For example, Gelman, Coley, Rosengren, Hartman, and Pappas (1998) found few explicit discussions about the underlying essence of category membership in their investigation of parents reading picture books with children. Gelman et al. found, instead, that parents used more subtle cues, such as gestures (e.g., linking two pictures with a sweep of the hand) and brief generic statements (e.g., "birds lay eggs") to guide children's understanding of shared category membership. It may be a mistake to conclude from this, however, that children's theory revision happens independently of explicit explanations from parents. Picture book reading is an activity with a particular structure and a typical discourse pattern that may not involve explanations. In the midst of other types of activities, however, children and parents may be likely to engage in explanatory conversations.

In this chapter, we will describe three types of studies using different methods to capture (for subsequent coding) the moments when natural explanatory conversations occur. First, we discuss studies using a diary method; second, we discuss a method of observing natural conversations in a museum setting; and third, we discuss a method in which we give parents and children a more focused task that is designed to elicit explanations about a particular domain. For each study we will describe the method and some of our findings regarding children's and parents' contributions to these causal conversations. Different methods emphasize different types of contributions. For example, the diary methodology we have used focuses on children's "why" questions as initiators of causal conversations. In contrast, when we explore parent-child conversations in a museum setting, the explanatory conversations we see seldom begin with a "why" question from a child. This underscores the importance of using multiple methods in order to obtain a more complete representation of the types of explanatory conversations in which parents and children are engaged. After discussing the three studies, we will consider a difficult open question regarding whether and how these conversations may have impact on children's cognitive development. We will explore both methodological and theoretical aspects of this question.

Children's "Why" Questions: A Diary Methodology

One method we have used to capture the moments when natural explanatory conversations occur is a diary technique, where we asked parents to keep track of their children's "why" questions and the conversations that followed. With this technique researchers are not present during the interaction to document all of the detail of the discussion, and we are limited by what parents remember or choose to report. But we do have the advantage with this technique of gathering data about the phenomena that puzzle and interest children enough for them to spontaneously seek explanations from the adults around them. Because children are creating these situations for themselves (rather than having them initiated by researchers, or even parents), they seem particularly revealing of children's own interests and motivations, and they may be particularly likely settings for conceptual change to occur.

The diary methodology also allows us to address two important methodological issues that arise in research with families from diverse backgrounds (for example, immigrant parents, parents with lower economic status, and parents with lower formal educational backgrounds). First, these parents may have a very different perception of the experimental setting than do middle-class, highly-educated white parents. We argue that looking at children's spontaneous "why" questions may be a method less prone to bias than other types of studies. Bringing a child and parent to a laboratory situation may be more uncomfortable for parents who are unaccustomed to university environments than asking them to keep track of their children's questions at home. Second, the diary reports can be collected through telephone interviews, eliminating potential difficulties related to parents' literacy.

The diary technique, by definition, focuses us on children's "why" questions. "Why" questions have been studied in great detail as a window on children's thinking. Piaget (1974) argued that "There is no better introduction to child logic than the study of spontaneous questions" (p. 171). In these diary studies, our focus goes beyond what children's questions tell us about what they are thinking, and also includes the conversational activities that emerge in response to these questions. Rather than focusing on what we can learn from children's questions, then, we focus on what children themselves might learn from having asked the question and engaged in the conversation that follows.
In previous work with mostly middle-income European-American families, we have found that preschool children ask "why" questions about complex scientific phenomena, and that parents' answers potentially offer guidance for children's theory development (Callanan & Oakes, 1992). (Children, of course, ask questions about non-scientific domains as well, but for the purposes of this chapter we consider only the questions about scientific domains.) Because some research suggests that scientific causal explanation may be more characteristic of middle-class Western communities (e.g., Rogoff et al., 1993), it is important to explore conversations in families of different cultural backgrounds. Previous research has suggested that questions and causal conversations may not be as common for Latino children as for children from European-American backgrounds (Heith, 1986). Delgado-Gaitán (1994), for example, argues that Mexican immigrant children may be taught that questioning adults is a sign of disrespect. However, Delgado-Gaitán also reports that in the Mexican-descent families she studied, there was a sharp division between school-related topics and other topics, with Mexican immigrant parents being very open to children's questions when they saw them as part of their schooling.) Other studies suggest that Latino parents with more formal schooling are more likely to use an "inquiry" style with their children (e.g., Laosa, 1980). This literature raises questions about whether the kinds of "why" questions documented in middle-class European-American families are likely to occur in Mexican-descent families, and whether they vary in frequency depending on parents' formal schooling. In an attempt to address these issues, we have been working with Mexican-descent families as well as European-descent families, and we have also looked at parents' educational background as a potentially important moderator variable.

In our diary study (Callanan, Pérez-Granados, Barajas, & Goldberg, 1999), forty-eight Mexican-descent families kept track of their children's "why" questions for two weeks. There were two groups, varying in years of mothers' formal schooling. The "higher education" parents had completed high school or completed at least some college (mean years of schooling=14). The "lower education" parents had not completed high school (mean years of schooling=seven). Willingness to participate in the study was high within both groups of parents. Parents from the "lower education" group were easier to identify because many of them lived in the same neighborhoods or attended Head Start programs. Families were also contacted through community groups, social service organizations, or word-of-mouth. Parents from the "higher education" group were contacted through a bilingual preschool, advertisements in a bilingual newspaper, and through word-of-mouth. Within each education group there were two age groups of children—a younger group (mean age=3:10, range 3:8 to 4:5) and an older group (mean age=5:2, range 4:7 to 5:11). For simplicity, we will refer to these two groups as three-year-olds and five-year-olds.

Considering our earlier data from Anglo families (Callanan & Oakes, 1992), as well as our data from higher and lower education Mexican-descent families (Callanan et al., 1999), we see a great deal of evidence that preschoolers' causal conversations exhibit curiosity and interest in making connections among things they experience in everyday life. Parents reported questions asked by their children on a wide range of topics, as shown by the examples in Table 1.

Table 1. Examples of Diary Questions

<table>
<thead>
<tr>
<th>MEXICAN-DESCENT FAMILIES, LOWER FORMAL EDUCATION (from Callanan et al., 1999)</th>
</tr>
</thead>
<tbody>
<tr>
<td>¿Cómo es que los peces están en el agua y no se ahogan? (4:3)</td>
</tr>
<tr>
<td>How come fish are in the water and they don’t drown?</td>
</tr>
<tr>
<td>¿Por qué tenemos? (5:8)</td>
</tr>
<tr>
<td>Why do we dream?</td>
</tr>
<tr>
<td>¿Por qué el niño no tiene dientes? (4:1)</td>
</tr>
<tr>
<td>Why doesn’t the baby have any teeth?</td>
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<tr>
<td>¿Por qué las nubes están pintadas de negro? (3:8)</td>
</tr>
<tr>
<td>Why are the clouds painted black?</td>
</tr>
<tr>
<td>¿Por qué flotan los aviones y no se caen? (5:5)</td>
</tr>
<tr>
<td>Why do airplanes float and not fall?</td>
</tr>
<tr>
<td>¿Por qué llueve? (3:11)</td>
</tr>
<tr>
<td>Why does it rain?</td>
</tr>
</tbody>
</table>

1. All questions asked in Spanish are translated and presented in both languages. Questions asked in English are presented in English only.
MEXICAN-DESCENT FAMILIES: HIGHER FORMAL EDUCATION
(from Callanan et al., 1999)

- Why can you only see the moon when it’s dark? (4:1)
- Why does the sun come out? (3:0)
- Why does the moon walk with us? (4:11)
- Why does it rain? (4:2)
- Why do people get cancer? (5:4)

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- Where does rain come from? (3:5)
- How do the firemen not get burned? (4:11)
- How come the moon is big and orange now but other times it’s little and white? (4:2)

Causal questions were not necessarily frequent events in all families (the average number of questions reported was approximately ten in a two-week period), but almost all of the children asked at least one of these questions. For this chapter, we consider a subset of children’s questions that were identified as "science" questions, that is, potentially related to natural phenomena, biological processes, or physical mechanisms (as compared with "social" questions, which were related to human behavior, mental states, and cultural or religious traditions).²

² The distinction between "science" and "social" topics is, admittedly, an arbitrary one. Children do not necessarily think of these as distinct domains, as suggested by Carey’s (1985) work, for example. We would argue, however, that the distinction is a meaningful one for the parents who are answering the questions. The questions about the natural and physical world also touch on topics that are more relevant to the focus of this volume. Further, when all of the questions are included in the analyses, the patterns of results are virtually identical (see Callanan, et al., 1999).

Children’s questions provide evidence of scientific thinking in several ways. They involve asking for causes of events, noticing patterns, and seeking definitions for new words. Sometimes children evidenced hypothesis-testing in their questions, as in the following example from Callanan and Oakes (1992):

- Child: Why does Daddy, James (big brother), and me have blue eyes and you have green eyes?
- Mother: You get your eyes from Daddy. (Said goodnight, and left the room.)
- Child: (Calling mother back into the room.) I like Pee-Wee Herman and he has blue eyes. Daddy likes Pee-Wee Herman and he has blue eyes. If you liked Pee-Wee Herman you could get blue eyes too.
- Mother: It would take more than liking Pee-Wee Herman to make my eyes blue. God gave me this color and it can’t be changed.
- Child: Could you try to like Pee-Wee Herman so we could see if your eyes turn blue?

This example is striking because, despite this four-year-old’s naive understanding of the potential causes of eye color, she shows a strong grasp of scientific method and variable manipulation. Young children are not likely to carve up the world along the lines drawn by scientific disciplines. The questions reported in these diary studies do show, however, that preschool children show great interest in many phenomena that adults would categorize in the fields of biology, physics, and other scientific disciplines.

Interestingly, there is very little evidence of difference in the questions asked by children from different ethnic or educational backgrounds. Despite predictions drawn from the literature then, the Mexican-descent children in our studies asked virtually the same types of questions as the Anglo children, regardless of the educational background of their parents (Callanan et al., 1999).

Because our focus is on co-construction of scientific literacy, we are interested not only in the questions children ask but also in the parents’ responses and the ensuing conversations. How might parents guide children’s understanding and interest in science? While explanatory conversations may be relatively rare events, we have found that when children ask
causal questions, parents are very likely to explain causal connections to
them. Parents' responses were coded into four categories:

1. Causal, including causal mechanism, e.g., "He got hurt because
he was hit by a car," as well as causal outcome, e.g., "You have a
mouth so you can eat."
2. Religious, e.g., "God made it that way."
3. Unexplained essence, e.g., "That's how ducks are made."
4. Non-causal, e.g., in answer to "How are babies born?" the
response was "The baby is in my stomach."

Parents of Anglo and Mexican descent, and parents from higher and
lower educational backgrounds, were all likely to provide causal answers
in their children's questions. For example, in the Callanan et al. (1999)
study with Mexican-descent families, an average of 56% of parents' responses to
children's questions were causal. The average percentage of the other response
types were: religious responses, 20%; unexplained essences, 17%; non-causal responses, 25%. The pattern of responses was
the same for the two groups of families, and similar to those found by Callanan
and Oakes (1992) for Anglo families.

Although children asked questions about a wide variety of topics, we
focus here on the conversations that emerged in our study of Mexican-descent
children from questions about two particular sub-domains of biology: (1) human birth and (2) human anatomy. These two sets of questions contrast with one another in interesting ways. The birth questions represent cases where children are asking for a causal explanation for an
event that is unclear to them (i.e., "Where do babies come from?"). whereas the anatomy questions seem somewhat more vague and open-ended (e.g., "Why do I have a mouth?"). At first glance, then, the birth questions may seem like better opportunities for parents to "teach" children something about biology. But, exploring these two sets of conversations revealed some unexpected patterns.

Birth Questions

Questions about how babies are born occurred in both education groups,
but it is interesting that in the lower-education group they were asked
roughly equally at both ages (33% of three-year-olds and 50% of five-
year-olds), while in the higher-education group, they were somewhat
more common in five-year-olds (50% of the children) than in three-year-
olds (8% of the children). The parents' answers to questions about where
babies come from varied in both groups. There were parents from both
educational backgrounds who reported that they didn't know how to
answer, or that they told children to "wait till they were older." There were
also parents in both groups who gave children accurate information—as
shown in the examples below, these answers usually did not provide very
extensive information about conception or the birth process, but they
provided some limited information about causal connections.

Niño: ¿De dónde vienen los bebés?
Madre: Del estómago.
Niña: ¿Por qué tanto tiempo tienen que estar ahí en el vientre?
Madre: Pues duran nueve meses para que crezca el bebé.
Niña: ¿Por qué cuando una persona está en la panza de la otra el bebé se hace una bolita?
Madre: Porque los bebés son chiquitos y la panza de la mamá es aún más chiquita, y por eso se hace una bolita.
Niña: ¿Por qué es que cuando un bebé está en otro bebé del estómago se hace un bebé?
Madre: Porque los bebés son chiquitos y la panza de la mamá es aún más chiquita, y por eso se hace una bolita.
Niño: ¿Por qué cuando una persona está en la panza de la otra el bebé se hace una bolita?
Madre: Pues duran nueve meses para que crezca el bebé.
Niña: ¿Por qué cuando una persona está en la panza de la otra el bebé se hace una bolita?
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Madre: Pues duran nueve meses para que crezca el bebé.

These conversations about where babies come from may suggest that
parents don't provide much guidance in children's theory building at this
young age. However, parents' answers to this particular type of question
may not be representative of their answers to other topics. Most parents
reported that these were particularly difficult conversations, and that they
were either uncomfortable about these questions or just confused about
how much detail to provide.

Anatomy Questions

Parents' answers to children's questions about human anatomy provide an
interesting contrast. These included questions about why people have certain body parts, (e.g., "Why do we have a mouth?") as well as questions about features of particular body parts (e.g., "Why do you have black hair and I have yellow hair?", "Why does her foot hurt?"). Anatomy questions were asked by 54% of the children with higher-education mothers, and 50% of the children with lower-education mothers (collapsed across age).

The proportion of causal explanations given to these questions was not significantly different across maternal education levels, though there was a trend for more causal responses in higher-education families (M=57%) than in lower-education families (M=30%).

Despite the fact that the anatomy questions seem quite open-ended, it is striking that in answering these questions, parents often directed children toward biological content. As some of the following examples show, many of these questions seemed to arise from events that children were questioning in a more "social" way, but parents' answers seem to have been focusing them toward the biological domain, for example by introducing words like "grow" or by describing developmental processes.

Mother: When children are born, they are born with little or no hair. Why doesn't this baby have teeth and the other child does?

Mother: Because you were younger then, you were a baby.

Mother: You're still growing. As you eat better and get bigger, they will start growing.

Child: How can I get boo-boos? [Breasts.] How come you have some and I don't?

Mother: You're still growing. As you eat better and get bigger, they will start growing.

While these questions focus on how things appear at the present time, it is interesting to see how often parents' answers draw children's attention to processes of growth, change, and birth. Using phrases such as "when you were a baby" or "you're still growing" may begin to help children delineate the domain of human growth and change. Because questions about body parts so often led to these sorts of discussions, children may learn from such conversations that body parts and appearance are connected to processes of growth and change. Although parents in this study did not report many complex scientific explanations, these anatomy conversations suggest that parents may guide children's theory development by helping them to pick out the relevant domain of explanation and by providing them with fragments of the puzzle of how to interpret different daily experiences in larger explanatory frameworks.

In sum, the diary studies provide us with some evidence that children's "why" questions invite parents to enter into explanatory conversations with them. These questions cover a wide range of topics that would fall into scientific disciplines. Parents and children from the different backgrounds studied so far seem to engage in very similar types of conversations. In addition to providing information about science, parents may also be guiding children's understanding of scientific domains by communicating to them evaluations about what kinds of things are important to know. In Goodnow's (1990) provocative discussion about the socialization of cognition, she suggests that researchers need to attend more to the subtle messages available to children regarding what are the appropriate and inappropriate things for them to know about. In responding to children's questions about birth, parents seemed to give the indirect message that children should not know much about this topic. When answering anatomy questions, however, parents seemed quite intent on having their children understand something about the process of human growth and development. There are likely to be differences across families and cultures regarding the kinds of knowledge that are valued. Interestingly, however, in the work we have done with European- and Mexican-descent families from different educational backgrounds, we have not seen differences in the value placed on the process of discovery. In informal interviews with parents as part of the diary studies, parents were virtually
uniformly positive in their opinions about the value of children's questions and in their willingness to provide answers.

Parents' Explanations: Conversations in a Museum

The second technique we have used to "capture" explanatory conversations is to observe families in a setting that provides motivation for parents and children to talk about scientific events and their explanations. In collaboration with Kevin Crowley, we have observed and videotaped parent-child conversations in a hands-on children's museum, the San Jose Children's Discovery Museum. This collaborative work is described more fully in Crowley's chapter elsewhere in this volume. Our goals in videotaping conversations that occur while families interact with exhibits are to see how often explanations occur and as well as to gain a better understanding of the dynamics of these conversations. While we don't expect every interaction in this setting to be focused on scientific explanations, the design of the environment may give us a better chance of capturing explanatory conversations here than in other settings. In our discussion we will refer to two data sets: one sample of 269 parent-child interactions across a variety of different museum exhibits, and a separate sample of 50 interactions at one particular exhibit, the "Take Another Look at Change" exhibit.

In the larger data set, the proportion of interactions in which parents gave an explanation was 25.6% overall. Three different types of explanations were identified: scientific principles, causal connections, and connections to prior experience. In the museum setting, unlike in the diary reports, we found that parents' explanations most often emerged in the absence of "why" questions from children. Consistent with the diary findings, though, parents' explanations seldom gave full accounts of scientific principles. Parents explained abstract scientific principles, for example introducing concepts like gravity, in only 12% of the explanations they gave. Instead, most explanations were identified as causal connections, which involved giving specific information about causes of a particular event (54% of the explanations given). The following example was recorded at a zoetrope exhibit: "Each one of those pictures is a little different pose on the horse, and it makes it look like it is galloping." As in the diary data, then, there seems to be a focus on helping the child to understand the particular event as it is happening rather than a focus on more abstract reasoning.

In the third explanation type, connections to prior experience, parents connected the present experience to the child's previous experiences. This happened in 25% of the explanations in the larger museum sample. An example recorded at a heartbeat exhibit was: "Remember the stethoscope at the doctor's? We can listen to your heart beat." This strategy of connecting an explanation to a child's previous experiences was also apparent in many of the parents' responses in the diary study. This strategy may be a particularly effective way to engage children in science topics. In Tharp's (1997) discussion of five standards for culturally relevant pedagogy, he proposes contextualization as one of the standards, and argues that contextualizing new information in children's experience is a necessary component of effective teaching. Consistent with the work of Moll and Gonzales (1994), Tharp also argues that contextualization may be particularly important when teaching children from culturally diverse backgrounds for whom middle-class schooling practices may be unfamiliar. Our data suggest that parents naturally use this effective strategy of contextualizing new information in children's prior experiences.

Beyond the explanations that have been discussed, another more subtle way that parents may guide children's developing scientific literacy is by helping children identify the domains of thought that are relevant to the events or activities in which they are engaged. Experience does not come parsed into domains. Within the context of the Children's Discovery Museum, parents have opportunities to help children interpret their experiences by guiding their attention to relevant features of novel and complex situations. In one exhibit (Figure 1), children and parents observe time-lapse photography of objects changing (e.g., plants growing, metal rusting, candles melting). As with most museum exhibits, and everyday life in general, the Take Another Look at Change exhibit affords multiple possible topics for engagement and conversation. In particular, parents can focus on the content of what is changing in the videos, or they can focus on the technology behind the production of the time-lapse videos. What parents choose to talk about is likely to influence children's focus of attention and their interpretation of what they are seeing. In other words, parents may be guiding children in terms of how to "parse" their experience at the exhibit.
The "Take Another Look at Change" Exhibit. a) This exhibit offers multiple possibilities for exploration and conversation. b) The video content component of the exhibit consists of several videotaped events depicting common objects undergoing change-of-state (e.g., plants growing, metal rusting, bananas rotting). c) The video technology component consists of the use of time-lapse photography to capture these change-of-state events, allowing museum visitors to observe often lengthy processes in just a few seconds.

Our analysis of 50 interactions at this exhibit supports the idea that parents play a role in parsing and interpreting events for their children. Of the parents we observed, 56% chose to focus exclusively on the content of the videos, discussing what was happening to particular objects over time (e.g., "The plant is dying; that's what happens when we don't water our plants.") and treating the time-lapse photography as transparent. Another 32% of the parents discussed both the change-of-state events and the technological process by which these events were captured (e.g., "This is time-lapse photography, where they put a camera on something for a really long time and then they sped it up really fast.")., and 12% of the parents did not engage in conversation while at this exhibit. None of the parents chose to focus on the time-lapse mechanism without mention of the change-of-state events. It is, perhaps, not surprising that parents found the content of the videos more salient than the medium that was used to present that content. The fact that some parents focused on the time-lapse technology does illustrate, however, that events can be interpreted in multiple ways. Parents talk to children in ways that may help children to understand the abstract domains that are relevant to the activities in which they are engaged.

When we investigated the ways that parents talked about the change-of-state events, we again found considerable variability in the talk. Twenty percent of the parents merely labeled the objects that were changing. More commonly, parents used descriptive or explanatory language in addition to labels for the objects. Thirty-six percent of the parents used change-of-state verbs, such as "grow" or "rust," to describe the events. This level of information not only provides children with an appropriate verb for observed changes, but may also help children to distinguish among events that are perceptually similar but result from different causes (e.g., a melting candle vs. a withering plant). Thirty-two percent gave even more explicit information about causal mechanisms for the changes that were occurring in the videotapes. For example, one parent said, "The beans died because they didn't get enough water." These parents provided the most detailed differentiation of causes for different events. This causal information could be very informative to children as they are learning about physical vs. biological changes.

Most museum exhibits, like most events in everyday life, do not fall neatly into one particular scientific domain. Parents' explanations often specify the relevant domain and help children to focus on what is important within the domain. We are still at the beginning of the process of trying to understand how children may be learning from parents' explanations. Some conversations suggest that children may be learning new ideas from their parents, as in the example below:

Parent: They stopped watering it. See what happened next, because there is no water.
Child: They all died?
Parent: Because they're not gonna get any water.
Child: Poor things!

Whether this child is really learning something new cannot be determined with certainty in such cases, however, and experimental studies are needed to address these questions more directly. Other conversations sug-
gest that certain explanations may not increase children's understanding of the phenomenon, as in the example below:

Parent: See that little clock in there? They're fast forwarding the growth of the potatoes.
Child: So they can make them grow faster?

This child's confusion was not cleared up in the conversation that followed. At times, parents may provide misleading or incorrect information to children.

This close inspection of parent-child interactions at a single exhibit not only demonstrates what parents do to structure the learning process, but also reveals ways that parents and children together co-construct understandings (or misunderstandings) within their interactions.

Parent-Child Discussions of Growth: Focused Parent-Child Tasks

The third technique we have used involves collecting data in more focused settings where parents and children are asked to engage in an activity where causal conversations are likely to take place. We will focus on one study in particular, in which we constructed a book that asked "What happened to the ...?" and showed various three-picture sequences of change-of-state events such as a mushroom growing, the moon changing shape, and a balloon deflating (Jipson & Callanan, 1999). The majority of the families in this study were from middle-income, European-American backgrounds. We expected parents and children to talk about causal explanations for the changes pictured in the book.

In this focused task, we found parents using many of the same strategies as in the museum study. Parents explained specific causal mechanisms rather than abstract scientific principles. Parents often referred to children's prior experience with similar events. And, parents often seemed to help children to identify the domain that is relevant to the events under discussion.

In an example from Jipson and Callanan (1999), a parent was helping her child explain changes of state, such as pictures of the moon in different phases:

Parent: Yeah, it's a full moon... Do you know why it's getting bigger?

Child: Because it's growing.
Parent: It's growing! Does this grow like mushrooms grow? (referring to a picture seen earlier in the book)
Child: Uh, yeah.
Parent: It grows in the dirt? I've never seen the moon in the dirt!
Child: No.
Parent: No, the moon is up in the sky!
Child: Yeah, Why did they grow up?
Parent: You know why it looks like it's growing?
Child: Um, hm.
Parent: You have asked me about this before. The earth is blocking it. It's a shadow so it gets bigger and bigger and bigger.
Child: Where's the shadow?
Parent: You can't see it...

This parent seemed somewhat surprised that her child appeared to think the moon actually grows. In her conversation she seems to be trying to find out whether her child really misunderstands. In doing so, this mother contrasts the apparent growth of the moon with the more familiar event of mushrooms growing. As this conversation unfolds, the parent not only provides information about the process of growth (as related to dirt), but also offers an alternative explanation of the phases of the moon as related to the physical movement of astronomical objects. Despite the fact that this parent is technically wrong about the reason for the moon's phases (a topic that is often seriously misunderstood by many adults), she does give the child information about the correct general domain for this event. Thus, as they negotiate meaning in a particular explanation, parents may guide children toward the "correct" domain by suggesting domain-appropriate forms of explanation. Further, as suggested by the above example, parents again connected the current discussion to the child's earlier experiences that were relevant.

In another example, Jipson and Callanan (1999) observed one mother attempt to explain crystal formation by saying, "It's kind of a rock that kinda grows. It doesn't really grow because it's not alive, but it grows..."

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3. As this parent suggests, the way the Moon looks in the sky is related to its position in relation to the Earth and the Sun. However, the phases of the moon are not caused by the Earth's shadow. Instead, as the Moon moves in its orbit around the Earth, our view of the side illuminated by the Sun changes. For example, when the Moon is between the Earth and the Sun, we can't see it because the light from the sun is hitting the side of the Moon away from the Earth (New Moon).
because it adds more and more of the rock to it.” In this example, the mother not only provides information about the ontology of crystals, but also suggests something about the domain-specificity of the process of growth. Interactions of this kind may help children negotiate their understandings of objects and events in the world, and consequently, can be considered to be a context for the construction and revision of intuitive theories.

Parents' conversations with children about scientific topics may vary in important ways depending on the activity setting in which the conversation takes place. This variability is very apparent in a comparison of the discussions of growth we observed in the museum vs. in the focused book-reading task. While 32% of the parents at the museum exhibit used at least one explanation, 98% of the book reading interactions involved at least one explanation. The explanations in the book reading task also tended to be longer and more involved. There are obvious reasons why parents focused more on explanations in the book-reading task, most notably because the book activity was defined by the researchers and the parents' goal was to participate in the research. In the museum, although they knew they were being videotaped, parents and children were negotiating their own goals and structuring multiple simultaneous activities. We see both activity settings as valid representations of some conversations that children engage in with parents. The book-reading conversations seem similar to some of the diary conversations, and may be representative of reflective situations in which children and parents focus on a particular topic for an extended time.

Of course, not all book-reading tasks are likely to elicit explanations, as mentioned in the earlier discussion of the work of Gelman et al., (1998). Our book clearly presented several phases in the change-of-state of an object and explicitly asked parents and children to discuss that change by asking “What happened to the...?” Gelman and her colleagues used a picture book that depicted objects varying in similarity, and did not provide text that would direct the conversation. Even within the genre of book reading, then, different kinds of conversational activity settings are encouraged depending on the content and goals of the book. In any case, taken together, the findings emphasize the importance of multiple methods in order to get a complete picture of the explanatory talk in which children and parents engage.

The Impact of Causal Conversations on Children’s Thinking

Overall, the studies described show that while parents rarely articulate complex scientific principles, they are providing other sorts of information that may well contribute to children's developing scientific literacy. In all three types of studies, parents seem to be providing fragments of explanatory information about particular events as children experience them. These fragments could potentially be used by children to construct causal theories. What remains open, however, is the more intractable question of whether these conversations are in fact influencing children's (and perhaps parents') understanding of scientific phenomena.

There are several difficulties to consider when attempting to address this question. First, it is not obvious what one would predict in terms of measurable impact of a particular explanatory conversation. We would not necessarily expect that a simple pretest-posttest design would be an appropriate test, given the complexity of human cognition. Instead, sociocultural theory would lead us to think about children's science understanding as emerging and being revised over many such interactions. Second, it is difficult for correlational findings to be convincing evidence of impact. We can look at individual differences in parents' styles of explanation and correlations with children's understanding of scientific topics. Even then, however, the direction of effect cannot be disambiguated. Parents who explain often may influence children's understanding, or children who understand scientific concepts may encourage their parents to explain. One possible solution to these problems is to investigate parent-child conversations on a particular topic over a period of time in a microgenetic approach, looking at more detailed and specific connections between parents' explanations and children's understanding.

One might ask how likely it is that the kinds of strategies we have uncovered will be found to have an impact on children's science understanding. As we have said, these are often “fragments” rather than full-fledged scientific explanations. Recent studies of scientific thinking, however, remind us that adults, and even adult scientists, do not think in terms of flawless scientific theories (Kuhn, 1996; Dunbar, 1997; Tversky & Kahneman, 1990). These explanatory fragments could, in fact, be more helpful to children than more complete causal explanations. As mentioned earlier, Gelman, et al. (1998) report in their monograph that parents rarely discussed the nonobvious features that differentiate different types of objects (such as animals vs. machines). In his commentary on that same monograph, Keil (1998) argues that the indirect ways that par-
ents in the Gelman et al. study discuss categories of objects may be much more appropriate to their children's level of understanding. Keil discusses the problem of "explanatory satiation," and argues that:

 Rather than try to load the child down with what would ultimately be an impossible burden of detail, the parent is instead showing the child how to approach various domains and allowing the child to proceed to discover the details at her own pace. (Keil, 1998, p. 152)

It remains to be seen what level of detail is most appropriate in explanatory conversations with children. Our findings seem to be parallel to those of Gelman and her colleagues, though, in that parents are providing systematic yet incomplete information about complex links among objects and events experienced by children.

Aside from the issue of the relative completeness of parents' explanations to children is the issue that parents sometimes even provide children with information that is incorrect or misleading. More research is needed to assess the potentially negative, as well as positive, effects of explanatory conversations. If our focus is on children's scientific literacy, rather than their knowledge of particular causal mechanisms, however, then the accuracy of particular comments may be less important than a discourse style that helps children figure out how to ask and find answers to questions. Even incorrect explanations may help children to explore their own ideas about a topic and to further their understanding in the long run.

Designing for Science

What can be learned from this research regarding the design of science education? Despite the open questions that remain, these findings are potentially relevant to early childhood educators, parents of young children, and designers of informal science education programs (e.g., museums).

There is a great deal of agreement among early childhood educators that academic skill-based instruction is not developmentally appropriate for young children (Elkind, 1986; Hirsh-Pasek, Hyson, & Rescorla, 1990). Instead, many educators prefer "developmentally appropriate practice" for preschool-aged children, which is defined by the National Association for the Education of Young Children (Bredekamp, 1987; Hart, Burts, & Charlesworth, 1997) as child-centered, exploratory, and contextualized. Our data support this approach to early education. In our studies, children's questions reveal their natural curiosity about the world (see also Gellman, 1995). Developmentally appropriate science instruction capitalizes on young children's natural curiosity; rather than focusing on the "right" answers, teachers engage children in the process of doing science. Interestingly, many of the authors of other chapters in this volume discuss models of science education that have much in common with this preschool model. While, traditionally, classroom science activities often convey a sense of science as objective and authoritative (Lemke, 1990), recent work on innovative science instruction shows that even adolescents' science learning should perhaps be more focused on students' spontaneous questions and process of discovery (e.g., Warren & Rosebery, 1996). Perhaps the design of science education programs, even for older children, should find better ways to make links with children's curiosity as a starting point for encouraging engagement with science topics.

Our findings speak to parents as well as teachers, suggesting that they can support children's science learning without intentionally focusing on instruction. Just by attending to children's spontaneous questions, and by commenting on their actions, parents may be making powerful contributions to their child's emerging scientific literacy. Consistent with Gelman et al. (1998), we do not very often see parents giving complex scientific explanations. But, consistent with the guidelines of developmentally appropriate practice and with Keil's (1998) arguments mentioned above, we would agree that school-like tutoring is not the best way to support young children's engagement in scientific thinking. Across groups of parents with very different educational and cultural backgrounds, we have generally seen a tendency for parents to respond to their children's curiosity in ways that are suggested by child development experts. In particular, they contextualize new concepts and experiences by relating them to familiar topics, and they follow their children's lead by taking their questions as an invitation to reflect on and discuss complex phenomena.

Finally, our data may also have some relevance for the design of informal science education programs. In the field of museum learning, constructivist theory has been very influential over the past several decades, leading to many hands-on interactive exhibits and to a philosophy that children are best left to explore exhibits on their own terms. Our findings support a slightly different approach to museum design, which is gaining popularity, and which is based on sociocultural theories such as Vygotsky's (1978; see also Schauble, Leinhardt, & Martin, 1998). In our work, parents' conversations with children about scientific topics seem to structure and guide children's interactions with exhibits in fruitful ways,
suggested that exhibits should be designed to increase the potential for interaction. As Crowley and Callanan (1998) argued, designing exhibits so that they foster parent-child interaction may increase the potential learning experiences for children in exhibits. Supporting parent-child involvement can be achieved in many ways. Even such mundane issues as whether there is a place for parents to sit near the exhibit can have an impact on the likelihood that meaningful interactions will take place. Precise decisions about how to improve the quality of interactions await further research and debate. For example, many complex decisions go into the design of signs to accompany exhibits. Parents may need to know something about how an exhibit works before they are able to give clear explanations to children. Signs that are too didactic, however, may lead to stilted conversations. Solutions to such problems will vary depending on the philosophy of the design team and the goals of the particular exhibit.

Conclusions

Across different projects, we are beginning to formulate a model of how explanatory conversations may impact children's learning. Parents are not often providing children directly toward reflective, abstract understandings of science. However, by focusing on particular events of interest in the moment, they may be giving children fragments of information that allow them to build up coherent understandings of particular events. What is strikingly similar across the conversations we have studied is that parents' explanations are likely to be focused on the particular event on which children are focused. Rather than trying to teach children an abstract principle, parents are likely to be providing a narrative of a particular experience. In line with Keil's (1998) argument about explanatory satiation, we would argue that this focus on specificity may be the appropriate level of focus for preschool children. The child may be able to gradually accumulate these understandings to develop a broader understanding of a phenomenon.

In addition to guiding children's understanding of specific causal mechanisms, parents are also modeling for children various aspects of the process of discovery in science: showing them how to formulate questions, find answers, and test predictions. Further, parents' explanations demonstrate for children that there is value in knowing about causes for events. Exploring these conversations is relevant to research and theory in several different areas in cognitive development and education. The "theory" approach in cognitive development focuses on children as little scientists, developing and revising theories of the world around them (Gopnik & Meltzoff, 1997; Wellman & Gelman, 1998). Studying children's conversations about science might help us to understand how children encounter evidence that leads them to change their theories over time. These conversations are also relevant to research in scientific reasoning. Although much of the research on science reasoning focuses on older children (e.g., Schaub, 1996), studying preschool children's thinking can tell us about the early development of such skills as hypothesis-testing and use of evidence. A third relevant research area is recent work on science education. As mentioned earlier, recent work in science instruction emphasizes the importance of social construction of scientific knowledge. Warren and Rosebery's (1996) work with Haitian immigrant students, for example, focuses on argumentation in the activity of doing science and shows that children's science learning can be more effective when taught in the context of collaboration (see also Brown, 1997; Greeno, 1998). By exploring the social contexts within which preschool children engage scientific ideas, we may be able to learn more about ways that this process of discovery can be extended and encouraged. Investigating whether and how these conversations vary across cultures will be very important in future research.

The results of our studies cannot, in themselves, tell us whether children learn new theories through conversation. A description of parents' explanations to children, however, is a starting place from which we can begin to consider the possibility that the process of discovery is not purely an internal matter. There are hints in these data about the possible ways that the social context and the cultural background of families create different environments within which children are learning about theory-relevant phenomena. The challenging next step is to find ways to assess the importance of these conversations for children's developing scientific literacy.

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