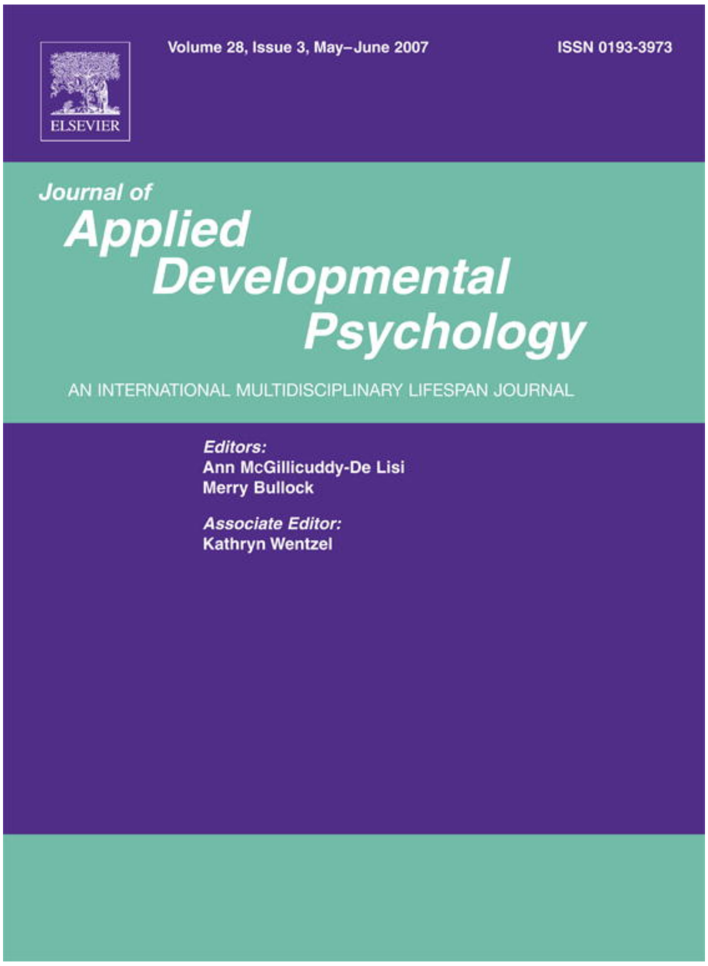

Volume 28, Issue 3, May–June 2007
ISSN 0193-3973

ELSEVIER

Journal of
Applied
Developmental
Psychology

AN INTERNATIONAL MULTIDISCIPLINARY LIFESPAN JOURNAL

Available online at www.sciencedirect.com
ScienceDirect
Journal of Applied Developmental Psychology 28 (2007) 189–210
Journal of Applied Developmental Psychology

How parent explanation changes what children learn from everyday scientific thinking

Jodi G. Fender, Kevin Crowley *

Learning Research and Development Center; University of Pittsburgh, United States

---

Abstract

Two studies examined how parent explanation changes what children learn from everyday shared scientific thinking. In Study 1, children between ages 3- and 8-years-old explored a novel task solo or with parents. Analyses of children's performance on a subsequent posttest compared three groups: children exploring with parents who spontaneously explained to them; children exploring with parents who did not explain; and children exploring solo. Children whose parents had explained were most likely to have a conceptual as opposed to procedural understanding of the task. Study 2 examined the causal effect of parent explanations on children's understanding by randomly assigning children to conditions in which they were or were not provided explanation while exploring a novel task with an adult. Children who heard explanations were more likely to switch from procedural to conceptual understanding. Results are discussed with respect to the role of everyday explanation in the development of children's scientific thinking.

Keywords: Parent–child activity; Explanation; Scientific reasoning; Informal learning; Museum learning; Everyday activity

---

1. Introduction

We explore the role of spontaneous parent explanation in shaping what children learn during everyday scientific thinking. Much of the research on children's scientific thinking, problem solving, and conceptual development has occurred in the context of laboratory studies of individual children working on tasks that have been designed by the researcher. Relatively few studies have explored scientific thinking and conceptual development in the context of naturally occurring everyday activity. Children in everyday settings often participate in scientific thinking in the company of their parents (Callanan & Jipson, 2001) where they negotiate the goals for problem solving, the strategies they use, and their criteria for completion. Parents also provide assistance to children, assuming greater control in areas where children are less competent and ceding control in areas where children are more competent (Gleason & Schauble, 2000). Although such guided participation in everyday settings has been identified as a common developmental context for children around the world (e.g., Gauvain, 2001; Rogoff, 1990), little is known about how specific patterns of parent–child interaction are linked to specific cognitive changes in individual children. In this

---

* Corresponding author. LRDC, 8th Floor, 3939 O'Hara Street, Pittsburgh, PA 15260, United States.
E-mail address: crowleyk@pitt.edu (K. Crowley).

0193-3973/$ - see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.appdev.2007.02.007

research we explore the impact of one particular pattern of parent–child interaction—parent explanation—on children's understanding of everyday activity.

Research on children's scientific reasoning processes suggests that children have difficulty coordinating the systematic collection of evidence with the construction of appropriate theories (Kuhn, 1989; Kuhn, Amsel, & O'Loughlin, 1988). Children often ignore new evidence if it is inconsistent with their existing theory, do not realize when their theories are flawed or incomplete, and design confounded tests of the effects of variables (Dunbar & Klahr, 1989; Klahr, Fay, & Dunbar, 1993; Schauble, 1996). Developments in evidence collection and evaluation are often described as internal metacognitive advances enabling children to monitor the systematicity of evidence collection, to seek out the most informative kinds of evidence and comparisons, to draw valid inferences about evidence, and to construct theories that are more internally consistent and that account for more of the available evidence (Klahr, 2000; Kuhn, 1989; Zimmerman, 2000).

However, despite the fact that young children are not systematic, exhaustive, or focused when collecting evidence, they nonetheless appear to do a good job building theories about everyday domains. For example, in the apparent absence of any direct instruction, children develop naïve mental models of the shape of the earth (Vosniadou & Brewer, 1992) and naïve theories about what fundamentally defines biological entities (Carey, 1985; Keil, 1989). The specific developmental mechanisms that produce change are still in debate; however children's theory development is often thought to result from the operation of internal, knowledge-based constraints (Wellman & Gelman, 1998).

We explored the hypothesis that parent explanations in everyday settings might be an additional source of guidance for children's cognitive development. It is common in developmental psychology for children's own explanations to be considered as a *measurement* of the current state of a child's knowledge; but we are interested in considering explanations as a *mechanism* that promotes cognitive development as opposed to an instrument that measures it (Callanan & Jipson, 2001; Chi, de Leeuw, Chiu & LaVancher, 1994).

In group problem solving, construction of collaborative explanations has been linked to problem solving success among adult dyads working on microworld science tasks (Okada & Simon, 1997) and scientists conducting cutting-edge molecular biology research (Dunbar, 1995, 2001). Studies of children's learning suggest that explanations are also associated with learning gains. When adults offer explanations as they demonstrate new problem-solving strategies, children are better able to transfer strategies to novel problems (Brown & Kane, 1988; Crowley & Siegler, 1999). Similarly, children are more accurate in constructing family-resemblance categories when adults provide causal explanations (Krascum & Andrews, 1998). If adults do not provide such explanations or at least explicitly prompt the child to generate their own explanations, it is unlikely that children will decide to do so on their own (Goncu & Rogoff, 1998; Siegler, 1995).

What does parent explanation look like in the context of everyday scientific thinking? In a recent study, families visiting a children's museum were videotaped as they used an interactive exhibit (Crowley et al., 2001). The exhibit was a zoetrope—a simple animation device with a series of animation frames inside a cylinder that spins. By spinning the zoetrope and looking through slots on the sides of the cylinder, visitors perceived, due to the stroboscopic presentation of individual frames, the illusion of motion. In this case, the animation was of a running horse. As they used the zoetrope with their children, parents were often observed to offer simple explanations. Examples included talk about causal links within the local context ("The horse looks like it's running backwards because you spun this thing the wrong way"), talk that made a connection between the exhibit and prior knowledge or experience ("This is how cartoons work"), and talk about unobservable principles underlying, for example, the illusion of motion ("Because your mind… your eye… sees each little picture and each one's different from the other one, but your mind puts it all in a big row").

These parent explanations were simple and short; none of them offered a complete accounting of the phenomenon and none of them would be considered formal, pedagogically correct scientific explanations (e.g., Leinhardt & Schwarz, 1997). Instead, parents were observed, in this study and in others, to use fragments of explanation: Suggesting how to encode evidence; highlighting individual causal links; offering simple analogies; and perhaps introducing relevant principles and terminology (Callanan & Jipson, 2001; Callanan & Oakes, 1992; Crowley, Callanan, Tenenbaum, & Allen, 2001; Gelman, Coley, Rosengren, Hartman, & Pappas, 1998).

What could children learn from these brief, incomplete explanations? It is probably not often the case that children adopt fully formed explanations that they hear their parents or other adults use. We propose that everyday parent explanation can instead provide children an on-line structure for encoding, storing, and making inferences about evidence as it is encountered. Although brief and incomplete, everyday parent explanations are well targeted to a moment of authentic collaborative parent–child activity. We hypothesized that they are powerful because they are offered when relevant evidence is the focus of joint parent–child attention. Although each individual explanation might be unlikely to catalyze a fully-realized moment of strategy shift, conceptual change, or theory development, the cumulative effect of simple parent explanation over time could be one of the direct mechanisms through which parents and children co-construct scientific thinking in everyday settings.

Consistent with this notion, emerging evidence supports the view that parent–child conversation during novel experiences plays an important role in how children understand and encode shared activity (Haden, Ornstein, Eckerman, & Didow, 2001). When parents ask questions, make connections to prior knowledge, encourage elaborations, and offer praise, the talk serves to focus children's attention on salient features of the activity. This talk often provides information that facilitates understanding and serves to organize children's resulting representations (Boland, Haden, & Ornstein, 2003). In everyday settings, Tessler and Nelson (1994) suggest that this talk assists young children in making sense of these shared experiences. Specifically, mothers who associated aspects of the shared activity with children' previous experiences had children who later remembered more about the activity than children of mothers who did not engage in these types of conversations.

In this article, we present two studies designed to link a specific pattern of parent support—simple parent explanation—to changes in children's understanding of one instance of everyday scientific thinking–exploring an interactive science exhibit in a children's museum. The two studies employed aspects of observational and experimental methodologies in order to study the kinds of spontaneous and authentic parent–child scientific thinking that have been described in previous naturalistic studies (Crowley, Callanan, Jipson, et al., 2001; Crowley, Callanan, Tenenbaum, et al., 2001), while at the same time allowing us to measure with some precision the state of children's knowledge following the experience. Similar to Dunbar (1995), we are concerned that when researchers bring tasks from the world into the laboratory for controlled study, they sometimes simplify to the point where essential properties of the activity become lost. Our prior observational studies of parent–child activity (e.g., Crowley, Callanan, Jipson, et al., 2001) are what Dunbar calls "in-vivo" studies—studies of everyday activity in real world settings. Although in-vivo studies provide windows into everyday activity, their lack of both control and random assignment precludes strong causal inference. In-vitro (traditional laboratory) studies, on the other hand, permit strong causal inferences via random assignment and control of variables, but they do not necessarily represent all essential features of everyday activity. Programmatic research that follows phenomena

Fig. 1. We studied children's exploration of the zoetrope exhibit at the Children's Museum of Pittsburgh. When children spin the zoetrope and look through the slots, they see an animation of a running horse.

from in-vivo to in-vitro settings (and back again) make us more certain that the tasks we bring into our laboratories do, in fact, generalize back to the true cognitive ecology of childhood.

Thus, in this article, we describe two studies that move progressively from everyday to more laboratory-like conditions. The scientific-thinking activity we examine in both studies was children's exploration of an interactive science museum exhibit-the zoetrope (Fig. 1). We chose the zoetrope because it provides a direct link to our prior in-vivo studies of parent-child scientific thinking. In Study 1 we extend this prior work by randomly assigning children to use the exhibit with or without parents and then pairing an observational study of in-vivo engagement with a systematic assessment of children's knowledge at the end of the activity. This design provides causal evidence about the effect of parent participation on children's exploration and it provides correlational evidence of the relation between parent explanation and children's understanding. Study 2 provides causal evidence about the effect of explanation on children's understanding. This study is fully in-vitro: Children are randomly assigned to hear either explanations or not while an experimenter leads them through a scripted interaction with the zoetrope. Learning is measured by differences from pre- to posttest. Taken together, these two studies and our prior work can be used to develop a mechanistic account of how simple parent explanation changes what children learn from everyday parent–child scientific thinking.

2. Study 1

The first study explored the impact of parent participation on children's exploration of and learning from an everyday moment of shared scientific thinking. The study included three comparison groups constructed from two conditions. First, children were randomly assigned to a condition where they engaged in everyday science activity solo or a condition where they engaged in the same activity with their parents. Second, we split the parent–child condition into two groups based on whether or not parents spontaneously offered explanations while engaging in the task. Thus, our analyses compare groups of children who used the zoetrope under three different levels of parent involvement: No-Parent (NP); Parent-No-Explanation (PNE); Parent-Explanation (PE). After exploring the device, all children were given an individual posttest that measured their knowledge of the zoetrope. The first part of the posttest was intended to measure children's procedural knowledge about how to use the exhibit itself. The second part of the posttest measured whether children understood the causal role of individual frames in an animation sequence. The third part assessed whether children encoded the zoetrope by its adult-intended function as an animation device or by the procedural function of spinning.

In order to most closely approximate in-vivo activity and support causal inferences about the role of parent participation on children's exploration, children in Study 1 were not given a pretest prior to engaging with the zoetrope. Any pretest that measured specific knowledge of the zoetrope or general knowledge about animation might have changed how children explored the device. Although the choice of having no pretest made Study 1 stronger with respect to measuring children's exploration, it necessarily made the study weaker with respect to measuring learning as a result of exploration. Still, we expected the posttest to provide a good approximation of learning because prior work suggested that many children would not come to the study knowing about the zoetrope—only about half of the children using the zoetrope by themselves were observed to spin it and look through the slots (Crowley, Callanan, Jipson, et al., 2001). In addition, pilot testing revealed that children were not typically at ceiling on posttest. But without a pretest to measure what children already knew about the zoetrope, we should note that Study 1 was not designed to support causal statements concerning children's learning. That was the role of Study 2.

We tested two predictions. First, we predicted that children who used the zoetrope with parents would explore more deeply than solo children. Based on prior findings we expected that most children would know to spin the zoetrope but that many would not know to look through the slots to perceive the illusion of motion without parent assistance. We did not predict differences between PE and PNE groups because we expected that explanations would introduce causal connections or suggest different encoding of the experience rather than provide procedural assistance.

Our second prediction was that PE children would be more likely than PNE and NP children to understand causal features of animation and to encode the zoetrope as an animation device. Specifically, we predicted that PE children would perform better than PNE and NP children on the posttest sections that assess their understanding of the role of animation frames and their encoding of the zoetrope as an animation device as opposed to a device that spins. These expectations were based on the idea that adult explanations are an important part of establishing intersubjectivity around an experience. Without hearing parent explanations, children may be more likely to base their interpretation of the experience on their own procedural activity rather than on the adult-intended interpretation for the task.

2.1. Methods

2.1.1. Participants

Participants were 64 families with children between the ages of 3- and 8-years-old who stopped at the zoetrope exhibit while visiting the Children's Museum of Pittsburgh. There were 26 boys and 38 girls. Thirty-five children were between 3- and 5-years old ($M = 4.26$ years, $SD = .78$ years), and 29 children were between 6- and 8-years old ($M = 6.76$ years, $SD = .74$ years). The study sample was generally representative of the museum population, which is predominately Caucasian and middle-class. Twenty-three children were randomly assigned to use the zoetrope by themselves and 41 children were assigned to use it with their parents. Roughly twice as many were assigned to the parent condition because, based on prior studies (Crowley, Callanan, Jipson, et al., 2001) and pilot work, we had expected about half of parents to spontaneously explain to their children. Thus, we anticipated that we would end up with three similarly sized groups for analyses—children with parents who explained, children with parents who did not explain, and solo children.

Parents of children in the PE and PNE groups answered questionnaires regarding how often the families visit the museum and their prior experience with the exhibit. Families in the PE and PNE groups reported similar habits of visiting the museum. It was the first visit to the museum for about 30% for both groups, 30% reported visiting twice each year or less, and about 15% reported visiting three times per year or more (25% of families did not provide this information). The zoetrope exhibit was in storage prior to data collection for both studies; therefore families would not have had any recent experience with the exhibit. Additionally, only approximately 18% of PE and PNE parents reported that they believed their children had seen the zoetrope previously.

2.1.2. Procedure

The study was conducted on weekdays during the summer. Informed written consent was initially obtained by researchers who greeted families as they entered the museum: 93% agreed to participate. Children were given stickers to wear that identified them as participants. The experimenter sat next to the zoetrope on the main floor of the museum. When participating families approached the zoetrope, additional verbal consent was obtained. If children approached without a parent, they were asked to go find their parents so that we could obtain the additional verbal consent. The experimental session included two parts: Engagement with the zoetrope and the posttest. The session lasted approximately 7 min and was videotaped.

2.1.2.1. Exploration. Families in the parent condition were asked to use the zoetrope together as they normally use museum exhibits and to call the researchers over when they were finished exploring. Parents of children in the no-parent condition stood nearby but off to the side with a research assistant, in order to let children use the zoetrope by themselves without any parent intervention. Previous research suggested that children using the zoetrope by themselves would sometimes choose to end their engagement in less than 60 s (Crowley, Callanan, Jipson, et al., 2001). To provide greater opportunities for children in the no-parent condition to learn, they were prompted once to continue exploration if they attempted to disengage before a minute had passed.

2.1.2.2. Posttest. The individual posttest was composed of three main parts. The posttest began with questions designed to assess children's knowledge about how to manipulate the exhibit. Children were first asked, "What did you see when you were playing with the zoetrope?" The zoetrope in the Children's Museum presented animation of a running horse. If children reported seeing horses but did not mention running, they were asked, "What was the horse doing?" The next question was, "If another little kid was here and she had never seen the zoetrope before, what would you have to tell her to do so she could see the horse run?" If children only mentioned one of the two necessary manipulations (spinning or looking through the slots), they were asked: "Is there anything else you have to do, or is that all?" The final questions on the first part of the posttest were: "Can you make the horse run faster? How?" and "Can you make the horse run backwards? How?"

Second, children completed a forced-choice test designed to reveal their understanding of animation. Children were shown two separate pairs of animation strips and asked to choose the strip that would work best. Each pair included a correct strip and a strip involving errors. After children chose a strip, the experimenter showed children the correct and error strips in the zoetrope and asked children which strip worked better and why. The first pair of strips tested whether children knew that each frame should be different in order to produce animation. The correct strip depicted a wheel rolling up and down a hill whereas the error strip had the wheel placed in the same position in every frame. The second pair of strips tested whether children knew that frames needed to be placed in a particular order to produce animation. The correct strip depicted a fish swimming around a fish bowl whereas the error strip contained the same frames but in the wrong order.

Finally, children completed an activity designed to assess whether they related the zoetrope to other objects that operate according to the same principles. The objects children saw shared either surface features with the zoetrope or operated according to similar principles (see Fig. 2). The surface-similar objects were a horse, a 'space ride', and a carousel with horses and other animals. These objects were chosen because of the horse inside the original zoetrope, because they could spin, or both. The principle-similar objects were different forms of animation: A flipbook, a 'picture stick' (thaumatrope), and a VHS videotape of The Lion King. (A thaumatrope is an object in which partial pictures on two sides of a card appear to merge when the card is flipped rapidly.)

In order to familiarize children with the objects, they were first shown each object in random order. Children were then successively shown three pairs consisting of one surface-similar and one principle-similar object and asked, after each pair, to choose the object that was more like the zoetrope and to explain why. We did not show children the pairing of the horse and thaumatrope because children might interpret the flipping of the thaumatrope as similar to spinning. Therefore, the principle-similar thaumatrope was only paired with the surface-similar spinning items (carousel and space ride). The particular pairings each child saw and the presentation order were randomized.

2.2. Coding

2.2.1. Parent talk

Coding of parent talk was done by pairs of coders directly from videotape. Rather than coding every utterance, coders listened for talk that was defined in the coding scheme as explanation, description, or direction. Pairs decided together whether the talk fit into those categories and marked down each instance of each of the three categories of talk. Explanations were transcribed for further classification and analysis. A primary coder worked with one of two coding partners. To determine reliability, an additional pair coded 20% of the data using the same procedure as the original coders.

Explanation was defined as talk that established causal relationships or made connections between the exhibit and prior knowledge. 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," or talk about unobservable causal processes underlying, for example, the illusion of motion: "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?" Connections included talk that made a link between the exhibit and prior knowledge such as, "Remember when we made the little comic book on the bottom of the page and you flip the

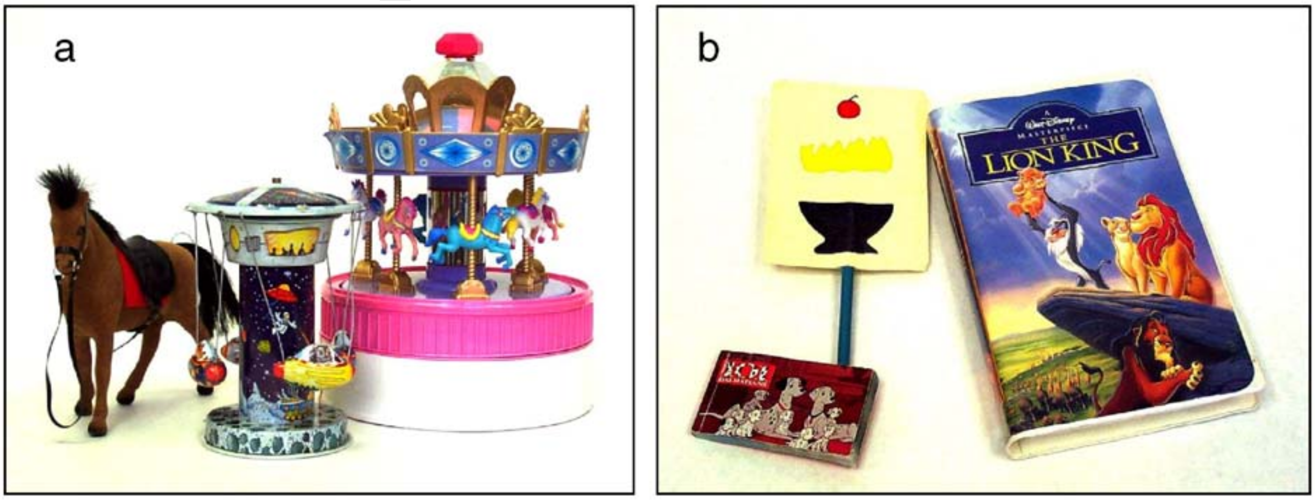

Fig. 2. Objects shown to children in Study 1. a) The surface-similar objects were a horse, a space ride, and a carousel. b) The principle-similar objects were a flipbook, a 'picture stick' (thaumatrope) and a VHS videotape of The Lion King.

whole notebook and it made it look like it was a moving cartoon? … I think this is the same kind of thing." Inter-rater reliability was 96%.

We also coded two additional kinds of talk. Direction was defined as talk about how to manipulate the zoetrope, such as, "Spin it the other way" or "Look through those slots." Description was defined as talk about information (i.e., evidence) that could be observed at the zoetrope that did not make causal connections or connections to prior knowledge. For example, "It looks like the horse is really running!" is an utterance that describes. Inter-rater agreement for both categories of talk was 86%.

2.2.2. Children's exploration

As children explore interactive exhibits, either simply to produce an effect or to understand how an exhibit works, they are provided with feedback about what does or does not work. We refer to this information or feedback as evidence and have adopted the convention of describing their exploration as movement through an evidence space (Klahr, 2000). As shown in Fig. 3, the evidence space for the zoetrope can be defined as the factorial combination of two dimensions: The rotational state of the cylinder (spinning or stopped) and the vantage point of the observer (through the slots or over the top). The animation has a unique appearance in each cell of the space and by comparing evidence available from different cells, children could collect sufficient evidence to infer that both spinning and looking through the slots are necessary to perceive the illusion of motion.

Children were coded as viewing a category of evidence if they visited that cell in the evidence space for at least 2 s. SlotSpin was coded if children looked at the animation through the slots of a spinning zoetrope, revealing the illusion of motion. TopSpin was coded when children looked down at the animation from over the top of the spinning zoetrope, revealing a spinning, but blurred, unanimated sequence of frames. SlotStop was coded when children looked at the animation through the slots of a stopped zoetrope, revealing a single still frame. TopStop was coded when children looked down at the animation from over the top of a stopped zoetrope, revealing a sequence of still frames. Inter-rater agreement was 91%.

2.2.3. Posttest

Videotapes of children completing the posttest were first transcribed. Two coders, each coding approximately half of the posttest transcripts, scored children's responses. The majority of the questions were scored either as incorrect or correct. Children's responses to "why" questions, requiring them to explain their choices or reasoning, were coded as either referring to animation or not. Prototypical responses were developed for each category to assist the coders with scoring. Inter-rater agreement was 95%.

	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

Fig. 3. 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.

2.3. Results

2.3.1. Parent talk

We first analyzed parent talk for the presence of explanation in order to divide families in the parent condition into those where parents explained to their children (PE group) and those where parents did not explain (PNE group). Twenty-four of 41 parents gave at least one explanation and the families were thus assigned to the PE group. Among parents in the PE group, 12 gave causal explanations, five gave connection explanations, and seven gave both.

It was possible that the presence of explanation would have been associated with richer parent-child conversation in general, thus potentially confounding comparisons of the presence or absence of explanations on children's understanding. Based on previous findings (Crowley, Callanan, Tenenbaum, et al., 2001), we expected that this would not be the case. To test this we conducted 2 (PE vs. PNE group) × 2 (older vs. younger group) ANOVAs on the number of parent directions and descriptions. There were no significant main effects or interactions. Children in the PE and PNE groups were equally likely to hear parent directions ($M = 1.5$ and $M = 1.7$, respectively) and descriptions ($M = 1.9$ and $M = 1.7$) Older and younger children heard roughly equal numbers of parent directions ($M = 1.7$ and $M = 1.5$, respectively) and descriptions ($M = 1.4$ and $M = 2.1$).

2.3.2. Children's exploration

To describe children's engagement with the zoetrope we measured the extent to which children encountered each of the four unique categories of evidence described by the factorial evidence space (recall Fig. 3). As shown in Fig. 4, children in the PE (79%) and PNE (82%) groups were more likely than children in the NP group (32%) to encounter SlotSpin evidence at least once, $\chi^2(2, N = 63) = 14.68, p < .01$. Of the four categories of evidence, SlotSpin is the most informative because it is the one cell in the evidence space where children observe the illusion of motion. For the remaining three categories of evidence there were no significant differences between groups.

There were also no differences in evidence exposure between age groups. Older and younger children were equally likely to see SlotSpin evidence (older 64%, younger 63%), TopSpin evidence (older 82%, younger 77%), TopStop evidence (older 68%, younger 57%), and SlotStop evidence (older 18%, younger 17%). All chi-squares were non-significant.

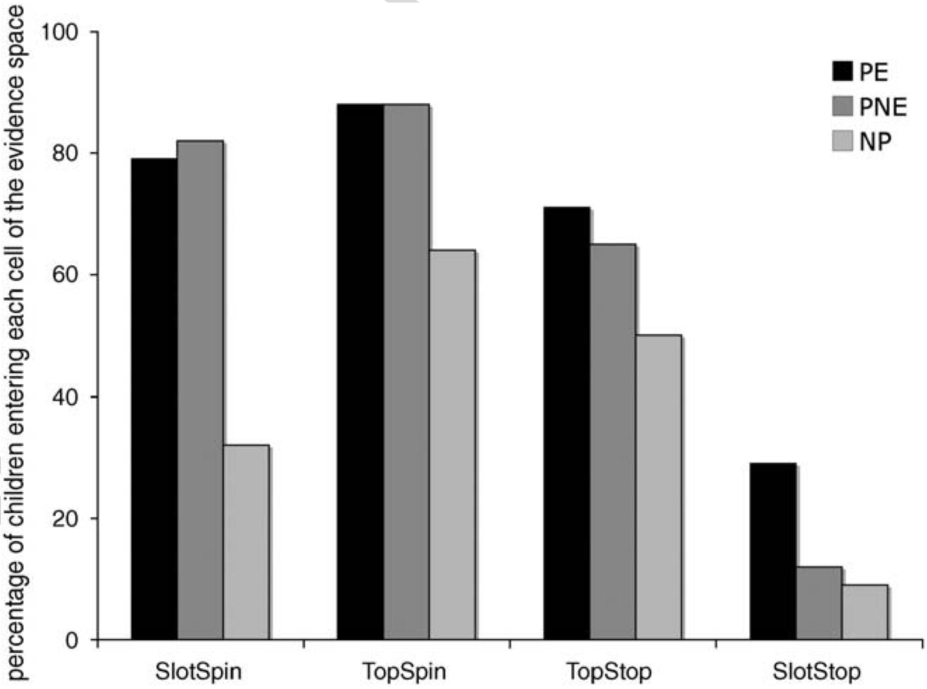

Fig. 4. Children whose parents were present (PE and PNE groups) were more likely to collect SlotSpin evidence—the cell of the evidence space in which the illusion of motion is visible. There were no significant differences between groups for other kinds of evidence.

2.3.3. Posttest

There were three main dependent measures computed from the posttest. The first measure reflected the posttest questions that tapped children's knowledge of how to use the zoetrope. We computed a composite score that could range from 0–5 by adding the number of correct responses to questions about whether children reported seeing the horse running, how they could make the horse run faster, how they could make the horse run backwards, and what would be necessary to teach to another child so that she could see the horse run. The second measure (ranging from 0–2) was computed from the posttest questions that assessed children's ability to recognize correct animation strips. Finally, the third measure (ranging from 0–3) was computed from the posttest questions that focused on children's ability to make connections to related devices and concepts. We first computed the three measures for each child based on their posttest response alone. We then computed the second and third measure again to reflect correct responses that were paired with correct justifications. Responses plus justifications provides stronger criteria for indicating that children know the correct answers.

Multivariate analyses of variance (MANOVAs) were performed first on children's responses to questions and then on responses plus justifications (Table 1). The MANOVA on children's responses indicated a main effect for level of parent involvement, $F(6, 112) = 2.89$, $p < .05$ and for age, $F(3, 56) = 16.31$, $p < .001$. The interaction of level of parent involvement and age was not significant, $F(6, 112) = .95$, *ns*. A MANOVA on children's justifications revealed a significant group–age interaction, $F(4, 114) = 2.78$, $p < .05$. Main effects were present for both level of parent involvement, $F(4, 114) = 4.76$, $p < .01$, and age, $F(2, 57) = 13.42$, $p < .001$. Follow-up ANOVAs on children's answers and justifications were performed on the three constituent posttest measures.

2.3.3.1. Part 1: How does the zoetrope function? A 2 (age group) × 3 (level of parent involvement) ANOVA on the composite score for part 1 revealed a main effect for age, $F(1, 63) = 14.38$, $p < .001$, but not for parent involvement, $F(2, 63) = 0.94$, *ns* (see Table 1 for means and standard deviations). Older children were better able to provide correct answers to questions about the exhibit, regardless of whether they were in the PE, PNE, or NP group. The interaction of age and level of parent involvement was not significant, $F(2, 63) = 2.66$, *ns*.

The five constituent measures of the composite score each followed this pattern except one. Regardless of the level of parent involvement, children were equally likely to report having seen the horse running (PE—88%, PNE—77%, NP—74%), $\chi^2(2, N = 64) = 1.49$, *ns*, to know how to make the horse run faster (PE—83%, PNE—88%, NP—87%), $\chi^2(2, N = 64) = 0.23$, *ns*, and to know how to make the horse run backwards (PE—75%, PNE—65%, NP—87%), $\chi^2(2, N = 64) = 3.15$, *ns*. Similarly, when asked to explain to a younger child how to use the zoetrope, all children were likely to report that they would tell the child to spin the zoetrope (PE-88%, PNE-82%, NP-91%), $\chi^2(2, N = 64) = 0.72$, *ns*. However, children in the PE group were the most likely to report that they would also tell the child that it is important to look through the slots (PE—46%, PNE—29%, NP—9%), $\chi^2(2, N = 64) = 8.03$, $p < .05$.

2.3.3.2. Part 2: How is animation created? A 2 (age group) × 3 (level of parent involvement) ANOVA on animation strip choices revealed a significant age difference, $F(1, 63) = 13.37$, $p < .01$, but no differences for level of parent involvement, $F(2,63) = 0.40$, *ns*. Older children chose the correct animation strip about twice as often, regardless of whether they were in the PE, PNE, or NP group. The interaction of age and level of parent involvement was not significant, $F(2, 63) = 0.03$, *ns*. Similar findings emerged when chi-squares were used to analyze performance for each pair of strips separately.

We then computed the number of correct justifications children provided for their choices. A 2 (age group) × 3 (level of parent involvement) ANOVA on animation reasons revealed a significant age difference, $F(1, 63) = 17.36$, $p < .001$,

Table 1
Study 1 posttest means (and standard deviations)

	Younger			Older		
	NP	PNE	PE	NP	PNE	PE
How zoetrope functions (out of 5)	3.20 (.92)	3.17 (1.34)	2.92 (1.50)	3.69 (.75)	4.00 (1.00)	4.82 (.41)
Animation strips (out of 2)	.70 (.48)	.58 (.67)	.77 (.44)	1.23 (.73)	1.20 (.45)	1.36 (.67)
Animation strip justifications (out of 2)	.10 (.32)	.17 (.58)	.14 (.43)	.62 (.51)	.60 (.55)	.91 (.70)
Animation object choices (out of 3)	.30 (.48)	.58 (.52)	1.15 (.80)	1.08 (.95)	1.40 (.89)	1.91 (.83)
Animation object justifications (out of 3)	.10 (.32)	0 (0)	.23 (.60)	.23 (.44)	.20 (.45)	1.45 (1.13)

but no differences for level of parent involvement, *F*(2, 63) = 0.74, *ns*. Older children were more likely to give correct justifications for correct choices, regardless of whether they were in the PE, PNE, or NP group. The interaction of age and level of parent involvement was not significant, *F*(2, 63) = 0.53, *ns*. When chi-squares were used to analyze justifications for each pair of strips separately, similar findings emerged. Thus, children's knowledge of the zoetrope and how animation is constructed did not generally differ between groups.

2.3.3.3. Part 3: Of what is the zoetrope an instance? The third part of the individual posttest focused on children's ability to make connections to related devices and concepts. Results for children's object choices are presented first, followed by results for children's reasoning.

As shown in Fig. 5, older children and children whose parents explained were most likely to make animation object choices. A 2 (age group) × 3 (level of parent involvement) ANOVA on the number of animation object choices revealed main effects for age, *F*(1, 63) = 15.10, $p < .001$, and level of parent involvement, *F*(2, 63) = 7.24, $p < .01$. Scheffé post-hoc comparisons revealed that children in the PE group made significantly more animation object choices than children in both the PNE and NP groups, who were not significantly different from each other. The interaction of age and level of parent involvement was not significant, *F*(2, 63) = .007, *ns*.

After choosing an object, children were asked why that object was more like the zoetrope. As shown in Fig. 5, there was a significant interaction such that older children whose parents explained were most likely to be able to provide an animation reason for their object choice. A 2 (age group) × 3 (level of parent involvement) ANOVA on number of animation object choice reasons revealed a significant group-age interaction for children's reasons for choosing the object *F*(2, 63) = 5.68, $p < .01$. Main effects were present for both age, *F*(1, 63) = 10.61, $p < .01$, and level of parent involvement, *F*(2, 63) = 9.88, $p < .001$. Scheffé post-hoc comparisons revealed that children in the PE group provided significantly more animation reasons than children in the PNE and NP groups, who were not significantly different from each other. Thus, although both older and younger children who received explanations were more likely to choose objects according to the adult intended function of the zoetrope, the younger children in this group were not able to provide an animation reason for their choice.

Why were children who heard explanations more likely to associate the zoetrope with other animation devices? It was sometimes the case that parent explanations included the explicit statement that the zoetrope was like movies or cartoons and thus children may simply have remembered that statement and chosen accordingly. However, of the 24

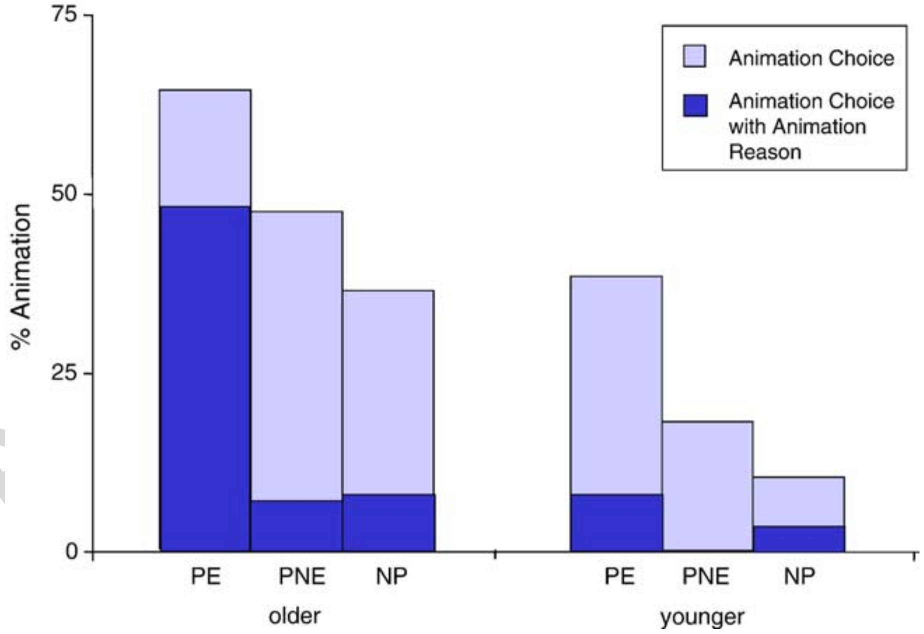

Fig. 5. Children whose parents explained were more likely to make animation as opposed to surface connections. This was true of both younger and older children. However, only older children whose parents explained were generally able to provide animation reasons to justify their choices. Younger children whose parents explained were likely to make animation choices, but rarely were able to explicitly justify why they did so.

children whose parents explained, only six heard parents use specific animation terms like “movie”, “cartoon”, or “animation”, suggesting that it was unlikely children were all making simple associations between words like “movie” and objects like the videotape. The remaining 18 children mostly heard explanations focused on causal links within the exhibit itself such as “When [the zoetrope] goes fast, they ride fast, when it goes slow, they ride slow.” When the six children who had heard explicit animation terms were removed from the analyses, children who heard other explanations were still more likely to associate the zoetrope with other animation devices ($M = 1.39$) than children who did not hear explanations ($M = 0.82$) or children without their parents ($M = 0.74$), $F(2, 57) = 3.33$, $p < .05$.

2.4. Discussion

Study 1 tested two predictions. The first was confirmed: Children who used the zoetrope with their parents explored more extensively than solo children. Specifically, PE and PNE children were more likely to observe animation while using the zoetrope and were more likely to report that both spinning and looking through the slots was important when using the zoetrope. This finding is consistent with the broader parent-child reasoning literature. In activities other than scientific thinking, parents are often observed to guide children’s search and focus their problem solving strategies on the most promising approaches (e.g., Gauvain, 2001). Gleason and Schauble (2000) have demonstrated similar parent assistance effects for prolonged experimentation tasks with older children (9–12-years-old). Our study extends the findings to young children using typical interactive exhibits of the kinds that are often found in science and children’s museums. With respect to our broader strategy of systematically translating a naturalistic task into the control of a lab-like study, it was important to demonstrate that one of the roles of parents, independent of whether they explain, is to encourage children to spend time exploring the most informative region of the evidence space. Prior studies of naturalistic family scientific thinking have not involved random assignment to parent vs. solo conditions and thus could not provide causal evidence for this conclusion.

The second prediction was that parent explanations would be associated with differences in children’s understanding of the zoetrope. This prediction had mixed support. Consistent with the prediction, children who heard explanations were more likely than other children to report that the zoetrope was similar to animation devices, suggesting that they had encoded it according to the intended conceptual function of animation as opposed to the procedural function of spinning. Thus, simple parent explanations may, in fact, change how children encode a scientific thinking experience. Although explanations may facilitate a conceptual encoding, this change does not necessarily represent a major shift from a functional focus to a conceptual focus, but rather moves children from describing the exhibit as being “about spinning” to “about animation.” Children whose parents explained are most likely to view the zoetrope’s function as being animation, rather than spinning. Replicating previous studies (Crowley, Callanan, Jipson, et al., 2001; Crowley, Callanan, Tenenbaum, et al., 2001), the explanations parents gave were simple, sketchy, and somewhat mundane. About half of the parents spontaneously offered these simple bits of explanation during exploration. It is important to note that there were no other significant differences in the activity of families where parents did or did not explain. Children with their parents typically showed broad and deep exploration of the device and parents typically talked about using the zoetrope and about evidence. Thus, findings suggest that the presence of explanation was the key difference in creating outcome differences on the encoding posttest.

However, two features of the design of Study 1, although necessary in order to most closely approximate in vivo scientific thinking, limited the study’s ability to support causal conclusions.

First, we chose not to include a pretest of child knowledge. Second, parents decided on their own whether to explain or not. Both of these features make it impossible to tell whether the explanation was responsible for differences in children’s encoding. We address both of these limitations in the design of Study 2.

The prediction that explanation would be associated with differences in children’s animation knowledge was not supported by the findings. The animation posttest assessed if children understood that all frames of an animation could not be the same picture and if they were able to distinguish a correct from a randomly ordered sequence of frames. In finding no difference due to parent explanation, we perhaps found that using the zoetrope may not have provided much opportunity for children to learn about how animation works. In retrospect, this does not seem surprising. Exploration of the device is mostly about spinning and looking through the slots to perceive the illusion of motion. We did not provide an opportunity for children to make their own animation strips or to experiment with faulty animation strips.

Finally, we considered age differences. There were no age differences in use of the exhibit: Both older and younger children were equally likely to encounter the four types of evidence. Yet older children did better than younger children on each of the three posttest sections. There are probably two factors at work here. First, we would expect that older children have had more opportunity to learn about animation than younger children. Whether they simply recalled this prior knowledge on the posttest or whether this prior knowledge served as the basis for making stronger inferences based on their use of the zoetrope, we would expect that children who know more coming into the study would know more at the end of the study. A second factor that could be at work (either independently or in interaction) is that older children are generally better than younger children at making valid inferences from evidence (Ruffman, Perner, Olson, & Doherty, 1993; Shaklee & Paszek, 1985; Sodian, Zaitchek, & Carey, 1991) and at encoding multiple features of a single device (Siegler, 1981). Regardless of the precise reason for the age difference, we note that explanations facilitated encoding for both older and younger children.

3. Study 2

Study 2 was designed to provide a causal link between explanation and changes in children's encoding. The most important differences from Study 1 include an implementation of a pretest and the random assignment of children to hear explanations or not by having an experimenter deliver scripted explanations. There were two additional changes as well. First, during pilot testing we found that because of the addition of a pretest, a lengthened posttest, and a longer experimenter-controlled interaction with the zoetrope, the procedure was twice as long as Study 1 and the youngest participants had difficultly completing it. Therefore, Study 2 includes participants aged 5–8 years old. Second, as described below, several posttest items were added or modified to better represent possible ways children might encode their understanding of zoetrope.

Our overall hypothesis was that children who heard adult explanations would be more likely to encode the zoetrope according to its intended animation function rather than its procedural features such as spinning. Based on the findings of Study 1, this overall hypothesis led to two specific predictions. First, we expected the pretest to show that most children begin with an understanding of the zoetrope based on the surface feature of spinning; that is, we did not expect most children to show animation encoding choices on the pretest. Second, we expected that children who heard the adult explanation would be more likely to shift to animation encoding on the posttest. Children who did not hear the explanation were predicted to maintain their original encoding from pre- to posttest.

3.1. Methods

3.1.1. Participants

Participants were 48 children between the ages of 5- and 8-years-old who were recruited during visits to the Children's Museum of Pittsburgh. The study was conducted on weekdays during the summer. There were 19 boys and 29 girls, who were divided into younger and older groups. Twenty-four children aged 5- and 6-years old were in the younger group ($M = 5.54$ years, $SD = .51$ years; 11 boys, 13 girls), and 24 children aged 7- and 8-years old were in the older group ($M = 7.54$ years, $SD = .51$ years; 8 boys, 16 girls). Half of the children in each age group were assigned to the explanation condition, and the other half were assigned to the no-explanation condition.

3.1.2. Procedure

Researchers obtained informed written consent either when families approached the zoetrope table or while they explored near-by exhibits. Parents watched from a near-by bench and did not interact with their children during the procedure.

3.1.2.1. Introduction to materials. The experimental session included four parts: A brief familiarization with the zoetrope, the pretest, the engagement with the zoetrope, and the posttest. The session lasted approximately 15 min and was videotaped. Immediately preceding the pretest, the experimenter familiarized the child with the exhibit according to the following script:

> "First I want to tell you that this is called a zoetrope. It has some slots to look through and some pictures to put inside. This strip has some horses, this one has a wheel on a hill, and this one has a goldfish in a bowl. I also want to tell you that the zoetrope spins around and does some other cool things that I will show you in a minute. But first I need you to help me figure some things out..."

3.1.2.2. Pretest. The pretest was composed of three parts. It began with children completing activities designed to assess whether they were able to relate the zoetrope to other objects that operate according to the same principles. This study included three sets of objects: Those that spun and were round, those with slots you look through to see something inside, and those that could produce animation (see Fig. 6). The round spinning objects were a top, a "space ride," and a carousel. The slot/content objects were boxes with removable covers with slots to look inside; they were constructed to have similar pictures to the animation strips the children were shown (horse, wheel on a hill, goldfish in a bowl). The animation objects were a flipbook, a "picture flipper" (thaumatrope), and a VHS videotape of The Lion King movie.

In order to familiarize children with the objects, they were first shown each object in random order. Children were then successively shown three triples, each of which included one spinning object, one slot/content object, and one animation object. They were asked, for each triple, to choose the object that was the most like the zoetrope and to explain their choice. The particular groupings and presentation order were randomized.

Second, children completed a forced-choice test designed to reveal their understanding of animation. Children were shown an animation strip with one frame missing. They were given three possible frames, asked to choose which was the missing frame, and asked to explain their choice.

Third, children completed a forced-choice test designed to reveal their understanding of the necessity of the zoetrope slots in producing animation. Children were shown pictures of two zoetropes (see Fig. 7). One looked like a typical zoetrope but could not produce animation because it had no slots, and one that was malformed but would still produce animation.

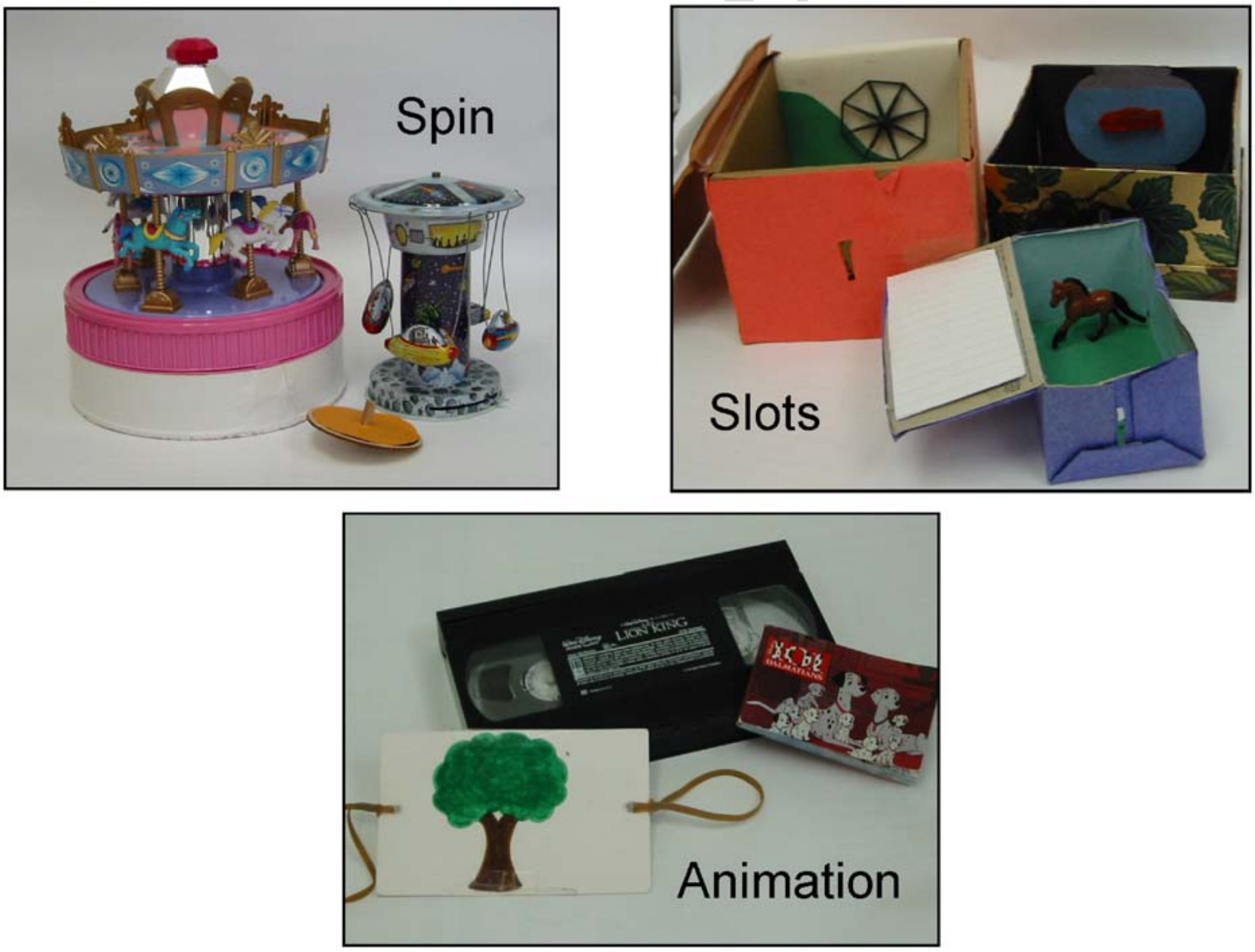

Fig. 6. Objects shown to children in Study 2. The Spinning objects were a top, a space ride, and a carousel. The Slots/content objects were boxes with slots to look through in order to see content that matched the three animation strips seen by children during the exploration of the exhibit. The animation objects were a flipbook, a 'picture stick' (thaumatrope) and VHS videotape.

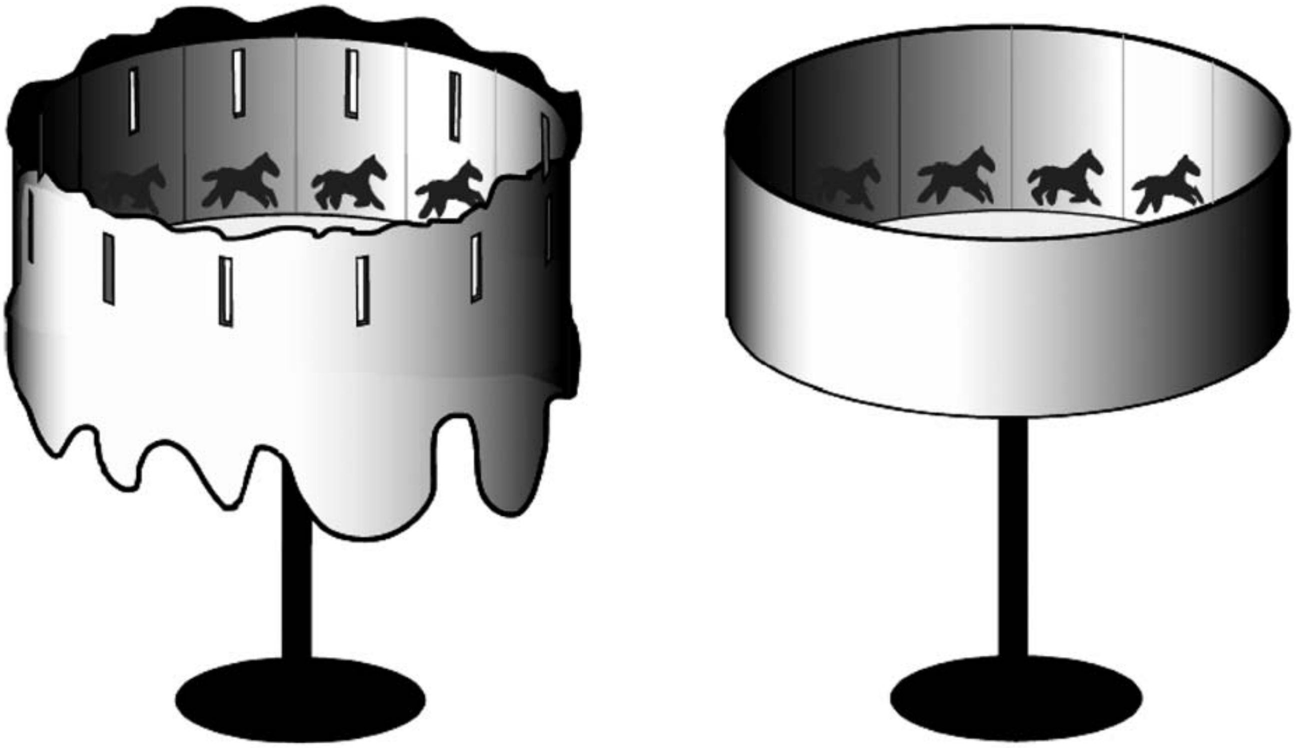

Fig. 7. Children were shown pictures of two zoetropes: one that was malformed but would still produce animation, and one looked like a typical zoetrope but could not produce animation because it did not have slots.

3.1.2.3. Engagement with the exhibit. Immediately following the pretest, the experimenter demonstrated how to manipulate the zoetrope. The experimenter began by showing each child all four cells of the evidence space. Children could then manipulate the zoetrope themselves and were shown two additional strips. As shown in the scripts in Table 2, the Explanation and No-Explanation groups had identical interactions with the zoetrope, with the exception of the three explanations inserted into the explanation condition script. The explanations were modeled on the range of spontaneous parent explanations observed in previous studies.

Table 2
Study 2 Scripts for Explanation and No Explanation groups

TopStop: Ok. First, I want you to look inside here—over the top…ok?
TopSpin: Keep looking, I am going to spin it …ok?
SlotStop: Now, see these slots? Let's look through there…ok?
SlotSpin: Keep looking…I am going to spin it.
Now you saw what the zoetrope does.
* Explanation 1 provided here for Explanation group
Why don't you play with this for a little bit …and then we'll put some other pictures in when you are ready.
Here is another strip we can put in the zoetrope. It has a wheel on a hill … let's see what it looks like.
* Explanation 2 provided here for Explanation group
Here is another one … a fish in bowl.
* Explanation 3 provided here for Explanation group

Explanations:
1: You see, when you spin this and look through the slots, it looks like the horse is running. This is like TV or a video. Each picture is a little bit different from the one in front of it so when you look through the slots your eye sees one picture at a time, but your brain puts it all together to make it look like it's *really* moving. You know what? This is how they make cartoons, too.
2: You see how each picture is a little different …when you look through the slots it makes it look like it is moving.
3: See how these are like little movies?

3.1.2.4. Posttest. The posttest consisted of three parts, identical to the pretest. To begin the posttest, children were told that they would be shown the same groups of things that they saw before and asked to pick the thing that they thought was most like the zoetrope and explain their choice. They were told that they either could pick the same things they picked before or they could choose different things. Children were then shown the same triples of objects in the same order as their pretest. For Parts 2 and 3, children were asked to choose the correct completion frame for the animation strip (with the completion frame in a different position) and asked to choose the functional zoetrope, as in the pretest.

3.2. Coding

The majority of children's responses to pre- and posttest questions were scored either as incorrect or correct from videotape. Children's responses to "why" questions were transcribed and were coded either as including animation content or not. Prototypical responses were developed for each response category to assist the coders with scoring. A second coder completed 20% of the reasons originally coded by the primary coder and 100% agreement was obtained.

3.3. Results

3.3.1. Encoding shifts

The first part of the assessment focused on whether children encoded the zoetrope primarily in terms of animation, spinning, or slots. Based on the prior finding of an association between explanations and animation encoding, we had predicted that most children would not identify the zoetrope with animation on the pretest and that the presence of explanation would be associated with increased animation encoding on the posttest.

The pretest findings provided mixed support of our prediction that children would not begin the session with animation encodings. Of the 48 children in the study, 31 (13 older and 18 younger) supported the prediction by providing no evidence of animation encoding on pretest. These children most often chose spinning objects as related to the zoetrope. Fifteen of the 18 young children made spinning choices on all three trials whereas the other three made both spinning and slot choices. Among the 13 older children, 10 made all spinning choices and three made both spinning and slot choices.

However, 17 of the 48 children (11 older and 6 younger) did not support the prediction in that they made at least one animation choice on pretest. Of these 17, two children (both older) chose animation on all three trials, four on two trials (all older), and 11 on one trial (five older). Most of the choices that were not animation were spinning. Thus, a minority of children did begin the study by considering animation as a possible encoding (Table 3).

The pretest findings suggest that our assumption that children in Study 1 learned animation encodings from the explanation may have been too simple. Instead, perhaps we should consider two types of change: (1) Children do not have an animation encoding and learn it through adult explanation and (2) Children maintain or strengthen selection preferences to favor an existing animation coding over other competing encodings.

To analyze shifts in encoding from pre-to posttest, we first conducted a 2 (explanation condition) × 2 (age group) ANCOVA on number of animation choices on posttest, with number of animation choices on pretest as a covariate. The analysis revealed a significant explanation by age group interaction, $F(1, 47) = 4.83$, $p < .05$. Older children in the explanation condition had the greatest number of animation object choices. Main effects were present for explanation condition, $F(1, 47) = 10.04$, $p < .001$, and for age group $F(1, 47) = 6.63$, $p < .05$. Thus, our prediction of explanations leading to animation encoding received strong support among older children and moderate support among younger children (Fig. 8).

Table 3
Study 2 Animation object choice and justification means (and standard deviations)

		Younger		Older	
		Explanation	No Explanation	Explanation	No Explanation
Choices	Pretest	.42 (.67)	.17 (.39)	1.00 (1.04)	.58 (1.00)
	Posttest	.67 (.89)	.17 (.39)	2.00 (1.12)	.42 (.79)
Justifications	Pretest	.08 (.29)	0 (0)	.58 (1.00)	.33 (.65)
	Posttest	.33 (.78)	0 (0)	1.75 (1.22)	.42 (.79)

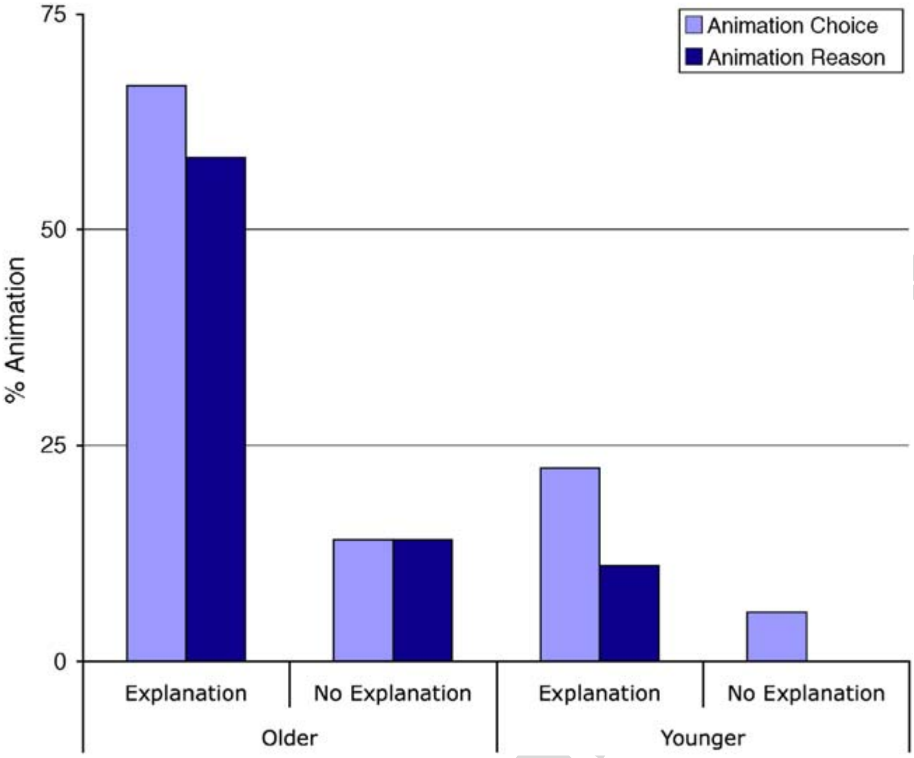

Fig. 8. Older and younger children who heard explanations made significantly more animation object choices and justifications of their choices.

After choosing an object, children were asked to explain why that object was most like the zoetrope. One might consider an animation choice paired with an animation reason as the strongest evidence that children's choices reflected their encoding preferences as opposed to random choices made in the absence of any true preferences. Analysis of choices and justifications yielded the same pattern as the analysis done on choices alone (Fig. 8). A 2 (explanation condition) × 2 (age group) ANCOVA on posttest animation justifications, with pretest animation justifications as a covariate, revealed a significant interaction such that older children in the explanation condition were best able to provide animation reasons for their object choices, $F(1, 47) = 4.33$, $p < .05$. Main effects were present for both explanation condition, $F(1, 47) = 6.35$, $p < .01$, and age group, $F(1, 47) = 8.56$, $p < .01$.

The ANCOVA results suggest that the presence of explanation was associated with increases in animation encoding, particularly for the older children. However, the analyses do not yet address the path of change: To what extent is change the result of children shifting preferences among existing competing encodings versus children learning new ways to encode the zoetrope?

To address this question we traced the path of change for children as a function of whether they started with animation as a possible encoding, whether they heard an explanation while using the zoetrope, and whether they ended the session with animation as the dominant response (Fig. 9).

First consider the path where children began with animation encoding on pretest, heard an explanation during the session, and then maintained or increased animation encoding on posttest (Fig. 9, Path 1). This path was most common among older children: Seven of the 12 older children in the explanation condition began with animation on pretest and all seven ended with animation dominant on posttest. Younger children were less likely to begin with animation encoding and, despite hearing explanations, were less likely to end with animation dominant: Four of the 12 began with animation and only one of these four ended animation dominant. Of the three who did not end animation dominant, two dropped to zero animation responses on posttest and the other maintained one animation response from pre- to posttest. Thus, for children who began the study entertaining the idea that the zoetrope was about animation, older children were significantly more likely than younger children to maintain or strengthen the idea in the presence of explanation, $\chi^2(1, N = 1) = 7.22$, $p < .01$.

A second possible path was for children to begin with animation and, without hearing an explanation, to end with animation dominant. This was not common. Of the six older and younger children in the No Explanation condition who began with animation, only one older child ended with animation dominant (Path 2).

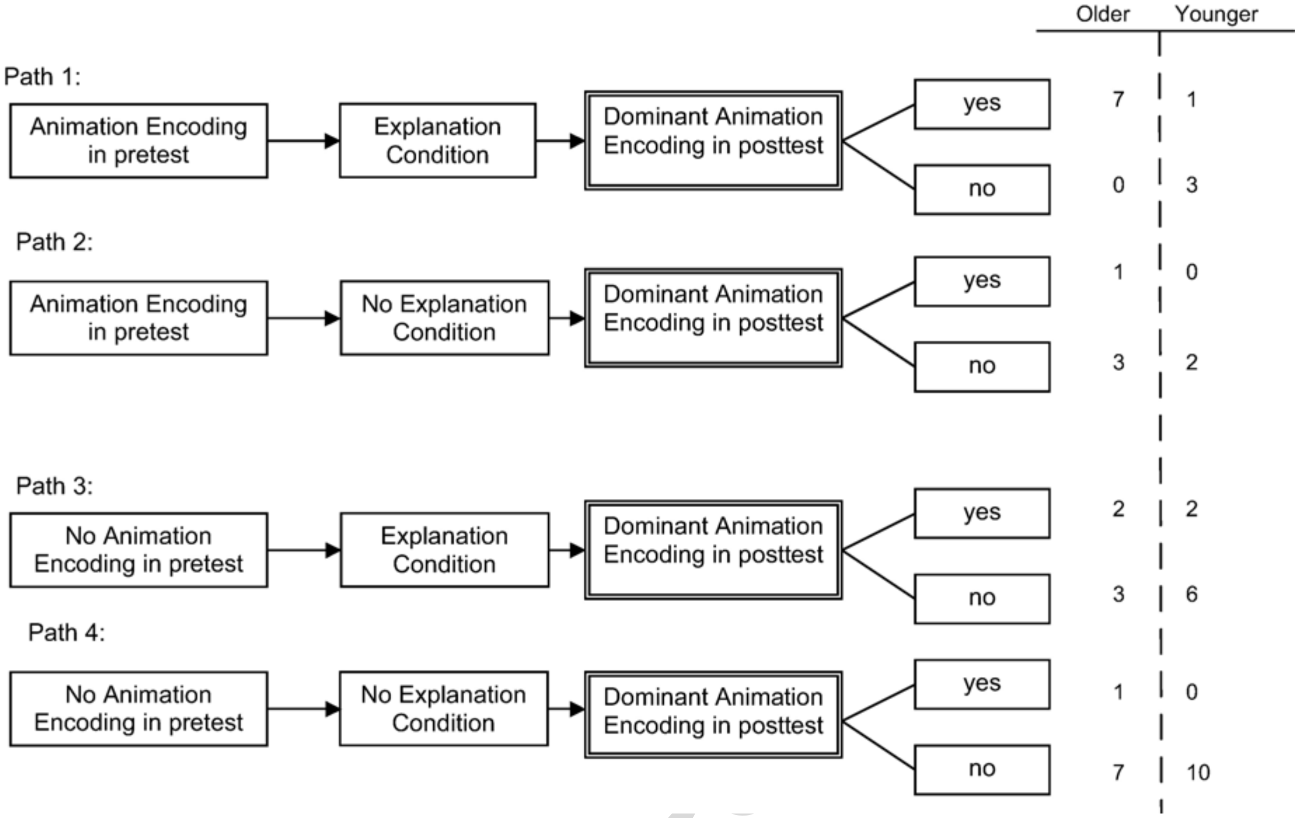

Fig. 9. The number of children following four possible paths that could lead to dominant animation encoding. These paths are characterized by whether children started the session with animation encoding and whether they heard explanation during the exploration of the exhibit.

A third path was for children to begin without animation, hear an explanation, and then use animation as the dominant encoding on posttest. In contrast to children on the first two paths, these children would be learning animation for the first time and then strengthening it to become the dominant encoding. Of the 13 children in the explanation condition who began without animation, four became animation dominant (Path 3). Among older children in the explanation condition, this third path was less likely to lead to animation dominant than the first path, $\chi^2(1, N = 12)$; $p < .05$. For younger children, the two paths were equally likely: 25% who began the path followed it to become animation dominant.

A final path was for children to begin without animation encoding, not hear an explanation, and then use animation as the dominant encoding. This was the least likely path: Only one of the 18 children in the No Explanation condition who started on this path followed it to animation dominant (Path 4).

In summary, the ANCOVAs identified a significant interaction between age and condition, with older children who heard explanations being most likely to encode the zoetrope as animation. Further analyses suggest that this interaction was driven in large part by explanations serving to strengthen or maintain existing animation encodings of the older children while failing to do so for the younger children. When older and younger children in the explanation condition began without animation encoding, they found it difficult to shift to animation as the dominant encoding, although some did succeed. Without hearing an explanation, children were unlikely to make an encoding shift.[1]

3.3.2. Knowledge about animation frames and the role of slots

The pretest and posttest included items that assessed whether children could choose the correct frame to complete an animation sequence and whether they understood that the slots were necessary to produce animation. Similar to the

---

[1] The paths depicted in Fig. 9 would fail to detect any changes in animation encoding on posttest that did not rise to the criterion of two out of three choices. It was possible that explanation may have helped children who began with no animation choices on the pretest to learn an animation encoding but not to generalize it to become the dominant response (i.e., these children would have shifted from zero pretest to one posttest animation choice). However, of the 26 children who did not begin with animation nor end with animation dominant (9 from path 3 and 17 from path 4), only one older and one younger child added the animation encoding but did not make it dominant. The other 24 children made zero posttest animation choices.

Study 1 findings, older children were more likely than younger children to recognize correct sequences of animation frames. On pretest, older children (88%) were much more likely to complete the sequence than younger children (38%), $\chi^2(1, N = 48) = 12.8, p < .001$. On posttest, the performances of older (83%) and younger (58%) children were more similar, although the difference still approached significance, $\chi^2(1, N = 48) = 3.63, p = .057$.

When asked to choose the functional zoetrope on pretest, children were equally likely to choose the one malformed but functional zoetrope regardless of whether they were in the older (21%) or younger (21%) group. By posttest however, the older children dramatically increased their performance (71%) whereas younger children (25%) did not, $\chi^2(1, N = 48) = 10.1, p < .01$.

There was no effect of explanation condition on either of these measures. On posttest, children in the Explanation (75%) and the No Explanation conditions (67%) were equally likely to complete the sequence correctly. Similarly, children in the Explanation (50%) and No Explanation (46%) conditions were equally likely to recognize that slots were necessary to produce animation.

All of these analyses were also conducted with correct responses plus correct justifications as the dependent measure and patterns were the same.

3.4. Discussion

Study 2 was designed to establish a causal link between adult explanation and children's encoding. In support of our hypothesis, findings suggested that children were more likely to encode the zoetrope according to the intended animation function when they heard the adult explanation. Almost two-thirds of children who ended up preferring the animation encoding on posttest began the session with animation as a possible but not preferred response. Older children were more likely than younger children to know animation on pretest and were also more likely than younger children to respond to the presence of explanation and end up with animation as the dominant response. The other one-third of children who ended up preferring animation encoding apparently learned it for the first time during their interaction with the zoetrope. There were no age differences on this path to learning.

As for knowledge about the roles of frames and slots, there was some suggestion that children learned as a result of the session, although there was no evidence that explanation facilitated that learning. Whereas older children knew about animation frames coming into the session and did not learn much more by posttest, one-fifth of the younger children learned something new by posttest. Both older and younger children were not clear about the role of slots on pretest. Younger children did not learn by posttest although half of the older children did.

What do these findings suggest about how adults and children negotiate meaning in shared scientific thinking? When children encounter novel devices in places like children's museums, they are generally engaged in hands-on exploration without much planning or reflection. They know that their role in such interactions is to make the device do something, not necessarily to figure out what the device is supposed to "teach" them. On their own, they are mostly likely to encode novel experiences in terms of possible manipulations and to focus on the affordances for action—in this case the slots and the spinning. Furthermore, without the explanation, the experimenter's talk to the child was all about spinning and slots. Children may have interpreted this as her communicating that the meaning of the experience was about spinning and slots, thus it reinforced their existing preferences and, in a few cases, encouraged children who began with animation preferences to adopt spinning or slot preferences.

However, when adults offer even simple explanations, they are making a bid to establish intersubjectivity within the ongoing activity. In activities such as the one we studied, this bid is about suggesting the broader meaning for what an experience is most directly connected to. We think this is probably a general function that adults often play in children's learning. By introducing an explanation, adults have expanded the set of possible competing ways of interpreting the situation, although they have not added any new evidence or experiences. One way to think about this is that an object's physical characteristics define its affordances for action; the adult conversation helps define its affordances for meaning making.

Why did younger children who heard explanations have more difficulty shifting their encoding than older children? One answer to this question is that younger children were less likely to begin the study already possessing a non-dominant animation encoding. Although few children in the study may have had prior experience with a zoetrope, we would expect that the older children have simply had more time to collect experiences that might be potentially relevant to the novel task. A second answer is that, even when younger children brought relevant experience to the task, they were less able than older children to shift their understanding toward the adult-intended function. Age differences often crop up in studies of scientific thinking among early elementary school children. For example, 7-year-olds outperform 6-year-olds on reasoning skills such as coordinating multiple pieces of evidence to design and evaluate a conclusive hypothesis test (Sodian, et al., 1991) or skills such as making new predictions concerning existing evidence and hypotheses (Ruffman, et al., 1993). In this study, the 5- and 6-year-old children may have been more focused on their existing encoding and less able to consider multiple simultaneous alternatives compared to the 7- and 8-year-old children.

4. General discussion

How does parent explanation change what children learn from everyday scientific thinking? We examined this question in the context of an open-ended scientific reasoning task. Our findings suggest both what changes as a result of parent explanation and what does not appear to change. What changed most often for children in our studies appeared to be the dominant understanding for how to encode the experience of using the zoetrope. Children who heard parent explanation were more likely to encode the experience as being about animation than children who did not hear explanation. What did not appear to change as a result of parent explanation was children's mechanistic understanding of animation and their procedural knowledge of how to use the zoetrope.

In general, we think these findings speak most directly to the literature on explanations and learning. Although it has not been uncommon for developmental psychologists to consider explanations, they have typically done so from different perspectives and in different contexts. Those interested in the effect of self-explanations on children's problem solving and knowledge construction have characterized explanations in terms of their effects on knowledge generation (e.g., Chi et al., 1994; Crowley & Siegler, 1999). Those interested in the structure and content of children's theories and mental models have focused on explanations as a way to assess current knowledge (e.g., Metz, 1991). Those interested in explanations as a naturally occurring element in parent–child discourse have focused on the processes but not often have directly assessed the outcomes (e.g., Callanan & Oakes, 1992). Although all of these lines of work explore the same mechanism–"explanation"–the functions, contents, forms, and the actors who are involved in producing and understanding explanations are different.

We see the current research as an incremental step toward the goal of bringing these three lines of work together to understand explanation as both a process and an outcome of cognitive development in a variety of contexts. Perhaps explanation is best seen as part of a continuum of that runs from contexts when problem solving or active exploration is the main focus of activity to contexts where reflection and conversation are the main focus. In each of the locations on this continuum, everyday explanation may serve a different function in terms of the development of scientific thinking.

At one end of the continuum are moments of the kind we have analyzed in the current research—moments when parents and children are primarily engaged in exploration and/or problem solving with explanatory conversations being a secondary, interpretive layer. Using interactive science exhibits in a museum is an excellent example of such activity, although children also encounter such moments when working to figure out how to use a new toy, put a puzzle together, use the computer, mix finger paints, build a sand castle, fix a bike, and so on. In these settings, successful execution of the activity itself is often the central goal. As we observed in this research, parents may also provide simple explanatory suggestions to help children make sense of the evidence as it is encountered. Although these suggestions did not necessarily impact the success of procedural outcomes (i.e., children mostly manipulated the device in the intended way), they did appear to change the way children marked the evidence they encountered (i.e., from "spinning and horses" to "animation"). This change is more consistent with the intended interpretation of the device—thus we were observing moments of enculturation where children's activity was shaped in a small but meaningful way to become closer to the intended adult interpretation.

At the other extreme of the continuum are moments where explanatory conversations and reflection are primary activities and the evidence under consideration is either not present or at least not being encountered for the first time. For example, Callanan and Oakes (1992) asked parents to write down the conversations that occurred in response to children's "why" questions. Many of the episodes parents reported occurred during activities such as bath time, bed time, meals, and riding in a car. The explanatory conversations revolved around topics such as why family members have different colored eyes, where cow babies come from, and why children are curious. In these examples, the particular activity was, in many ways, irrelevant to the particular conversation. Going to bed or eating dinner provided a convenient location for families to wonder and talk, but the talk itself was not in direct service of completing the activity. Perhaps in part because relevant evidence was not available in the situation and perhaps in part because having a conversation was a primary goal of the interaction, the explanatory talk parents reported was richer and more complete than the brief explanatory fragments observed in this research.

Toward the middle of the continuum are settings where children are observing and sometimes talking about evidence, although they are not primarily responsible for generating the evidence. These are settings such as reading a book with a parent or helping a parent who is fixing a sink or planting a vegetable garden. In these situations children may not be capable of performing the activity by themselves; they are much more clearly in the role of apprentices or legitimate peripheral participants. In these situations, conversations may also be a primary means of carrying the activity. When parents and children read storybooks, for example, parents often label, ask questions and sometimes explain to help children make sense of the story (e.g., Gelman et al., 1998).

As one moves from one end of this continuum to the other, at least three relevant characteristics of parent explanation change: 1) Evidence becomes less direct and less available; 2) Conversation becomes more common, more extended, and more of a primary goal for the interaction; and 3) Explanations become more intentional and more complete.

Clearly, within any single domain parents and children may participate in many moments of learning that might be placed at different locations on the continuum. For example, an individual child may very well develop expertise in the dinosaur domain by exploring a museum or playing with plastic dinosaur toys, by reading books about dinosaurs with her parents, and by having conversations about dinosaurs while riding home from day care or eating dinner. The nature and function of parent explanation may be different in each of these settings, but it is important to note that these are differences in degree, not in kind. Each of these moments builds upon the others and extends a broader set of explanations the parent and child are developing in collaboration over time (Crowley & Jacobs, 2001).

The broadest context for such a continuum and for our studies of collaborative parent–child scientific thinking may be around questions of how parents and children construct shared understanding about events, objects, and ideas. Experiences such as using interactive science exhibits in a museum are in some ways unusual and in other ways mundane. Although families may not encounter zoetropes every day, they do encounter novel object and novel experiences where they explore to figure out how something works and they do often talk to construct meaning around new experiences. The parent–child literature has often focused on the role of parents in helping children accomplish activity, solve problems, or use new strategies (e.g., Freund, 1990; Gauvain, de la Ossa, & Hurtado-Ortiz, 2001; Saxe, Guberman, and Gearhart, 1987). Beyond the issue of helping children be successful at an activity, some work has begun to focus on the role that parent talk might play in annotating children's observations and experiences to achieve intersubjectivity and bring parent and child understanding into alignment (Rogoff, Paradise, Arauz, Correa-Chavez, & Angelillo, 2003) or to make the shared experience more easily remembered (Boland, et al., 2003). We think this role of parent talk—making experiences in ways that communicate interpretation—may be a central mechanism of constructing shared understanding across many domains, including scientific thinking.

In conclusion, if we are to understand how scientific thinking develops in young children, it may be helpful to study children's learning in the contexts where it occurs and at the time-scales where it occurs. The current research presents an analysis of one kind of naturally occurring activity that is part of the everyday collaborative scientific thinking of many children. The two studies in this article were built directly off of our prior in-vivo studies; each of the current studies introduced increasing precision and control in order to explore a causal mechanistic question while at the same time preserving essential elements of the everyday activity. We identified one immediate outcome of children hearing an adult explanation while exploring a novel device—children shifted their encoding of the experience to make it consistent with the adult explanation. Recent microgenetic studies suggest that cognitive change is most often gradual and wave-like, with newly discovered strategies and concepts becoming gradually dominant while established competitors fade as they prove less effective over time (e.g., Chen & Siegler, 2000; Schauble, 1996; Siegler, 1996). The short moments of scientific thinking that we analyze here are best seen as examples of the types of small changes that make up the developmental patterns that occur across time and over multiple contexts as children participate in normal activities with their families, with their peers, with their teachers, and by themselves. Whether at a museum exhibit or at home figuring out how a new toy works, moments of shared scientific thinking, like the observed explanatory conversations between parents and children exploring the zoetrope, have a small effect on children's thinking and interpretation in the short term; however, these moments may potentially accumulate to affect the processes of children's scientific thinking and the content of their developing theories, concepts, and mental models.

Acknowledgement

This research was supported by grants from the National Science Foundation (ESI-9815021) and a Student Research Award from the University of Pittsburgh School of Education.

Thanks to Jane Werner and the staff of the Children's Museum of Pittsburgh and to Erin Guthridge, Erin Tully, Kelli Millwood, and Katie Wilkinson for data collection and coding assistance.

References

Boland, A. M., Haden, C. A., & Ornstein, P. A. (2003). Boosting children's memory by training mothers in the use of an elaborative conversational style as an event unfolds. *Journal of Cognition and Development*, *4*(1), 39−65.

Brown, A. L., & Kane, M. J. (1988). Preschool children can learn to transfer: Learning to learn and learning from example. *Cognitive Psychology*, *20*, 493−523.

Callanan, M. A., & Jipson, J. (2001). Explanatory conversations and young children's developing scientific literacy. In K. Crowley, C. D. Schunn, & T. Okada (Eds.), *Designing for science: Implications from everyday, classroom, and professional science* (pp. 21−50). Mahwah, NJ: Lawrence Erlbaum Associates.

Callanan, M. A., & Oakes, L. A. (1992). Preschoolers' questions and parent's explanations: Causal thinking in everyday activity. *Cognitive Development*, *7*, 231−233.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Chen, Z., & Siegler, R. S. (2000). Across the great divide: Bridging the gap between understanding of toddlers' and older children's thinking. *Monographs of the Society for Research in Child Development*, *65*(2).

Chi, M. T. H., de Leeuw, N., Chiu, M. H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science*, *18*, 439−477.

Crowley, K., Callanan, M., Jipson, J., Galco, J., Topping, K., & Shrager, J. (2001). Shared scientific thinking in everyday parent–child activity. *Science Education*, *85*, 712−732.

Crowley, K., Callanan, M. A., Tenenbaum, H. R., & Allen, E. (2001). Parents explain more often to boys than to girls during shared scientific thinking. *Psychological Science*, *12*, 258−261.

Crowley, K., & Jacobs, M. (2002). Islands of expertise and the development of family scientific literacy. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 333−356). Mahwah, NJ: Lawrence Erlbaum Associates.

Crowley, K., & Siegler, R. (1999). Explanation and generalization in young children's strategy learning. *Child Development*, *70*, 304−316.

Dunbar, K. (1995). How scientists really reason: Scientific reasoning in real-world laboratories. In R. J. Sternberg & J. E. Davidson (Eds.), *The nature of insight* (pp. 365−395). Cambridge: MIT Press.

Dunbar, K. (2001). What scientific thinking reveals about the nature of cognition. In K. Crowley, C. D. Schunn, & T. Okada (Eds.), *Designing for science: Implications from everyday, classroom, and professional science* (pp. 115−140). Mahwah, NJ: Erlbaum.

Dunbar, K., & Klahr, D. (1989). The developmental differences in scientific discovery. In D. Klahr & K. Kotovsky (Eds.), *Complex information processing: The impact of Herbert A. Simon* (pp. 109−143). Hillsdale, NJ: Lawrence Erlbaum Associates.

Freund, L. (1990). Maternal regulation of children's problem solving behavior and its impact on children's performance. *Child Development*, *61*, 113−126.

Gauvain, M. (2001). *The social context of cognitive development.* New York: Guilford Press.

Gauvain, M., de al Ossa, J. L., & Hurtado-Ortiz, M. T. (2001). Parental guidance as children leard to use cultural tool: The case of pictorial plans. *Cognitive Development*, *16*, 551−575.

Gelman, S. A., Coley, J. D., Rosengren, K. S., Hartman, E., & Pappas, A. (1998). Beyond labeling: The role of maternal input in the acquisition of richly structured categories. *Monographs of the Society for Research in Child Development*, *63*(1).

Gleason, M. E., & Schauble, L. (2000). Parents' assistance of their children's scientific reasoning. *Cognition and Instruction*, *17*, 343−378.

Goncu, A., & Rogoff, B. (1998). Children's categorization with varying adult support. *American Educational Research Journal*, *35*, 333−349.

Haden, C. A., Ornstein, P. A., Eckerman, C. O., & Didow, S. M. (2001). Mother–child conversational interactions as events unfold: Linkages to subsequent remembering. *Child Development*, *72*, 1016−1031.

Keil, F. C. (1989). *Concepts, kinds, and cognitive development.* Cambridge, MA: MIT Press.

Klahr, D. (2000). *Exploring science: The cognition and development of discovery processes.* Cambridge, MA: MIT Press.

Klahr, D., Fay, A. L., & Dunbar, K. (1993). Heuristics for scientific experimentation: A developmental study. *Cognitive Psychology*, *25*, 111−146.

Krascum, R. M., & Andrews, S. (1998). The effects of theories on children's acquisition of family-resemblance categories. *Child Development*, *69*, 333−346.

Kuhn, D. (1989). Children and adults as intuitive scientists. *Psychological Review*, *96*, 674−689.

Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). *The development of scientific thinking skills.* Orlando, FL: Academic Press.

Leinhardt, G., & Schwarz, B. (1997). Seeing the problem: An explanation from Polya. *Cognition and Instruction*, *15*, 395−434.

Metz, K. (1991). Development of explanation: Incremental and fundamental change in children's physics knowledge. *Journal of Research in Science Teaching*, *28*, 785−797.

Okada, T., & Simon, H. A. (1997). Collaborative discovery in a scientific domain. *Cognitive Science*, *21*, 109−146.

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context.* New York: Oxford University Press.

Rogoff, B., Paradise, R., Mejia Arauz, R., Correa-Chavez, M., & Angelillo, C. (2003). Firsthand learning through intent participation. *Annual Review of Psychology*, *54*, 175−203.

Ruffman, T., Perner, J., Olson, D., & Doherty, M. (1993). Reflecting on scientific thinking: Children's understanding of the hypothesis–evidence relation. *Child Development*, *64*, 1617−1636.

Saxe, G. B., Guberman, S. R., & Gearhart, M. (1987). Social processes in early number development. *Monographs of the Society for Research in Child Development*, *52*, 3−162 (2, Serial No. 216).

Schauble, L. (1996). The development of scientific reasoning in knowledge-rich contexts. *Developmental Psychology*, *32*, 102−119.

Shaklee, H., & Paszek, D. (1985). Covariation judgment: Systematic rule use in middle childhood. *Child Development*, *56*, 1229−1240.

Siegler, R. S. (1981). Developmental sequences within and between concepts. *Monographs of the Society for Research in Child Development*, *46*, 1−84.

Siegler, R. S. (1995). How does cognitive change occur: A microgenetic study of number conservation. *Cognitive Psychology*, *25*, 225−273.

Siegler, R. S. (1996). *Emerging minds: The process of change in children's thinking.* New York: Oxford University Press.

Sodian, B., Zaitchek, D., & Carey, S. (1991). Young children's differentiation of hypothetical beliefs from evidence. *Child Development*, *62*, 753−766.

Tessler, M., & Nelson, K. (1994). Making memories: The influence of joint encoding on later recall by young children. *Consciousness and Cognition*, *3*, 307−326.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*, 535−585.

Wellman, H., & Gelman, S. (1998). Knowledge acquisition in foundational domains. In D. Kuhn & R. S. Siegler (Eds.), *Handbook of child psychology: Cognition, perception and language* (pp. 523−552). New York: Wiley.

Zimmerman, C. (2000). The development of scientific reasoning skills. *Developmental Review*, *20*, 99−149.