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Explain This, Explore That: A Study of Parent–Child Interaction in a Children's Museum

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Parents visiting a gear exhibit at a children's museum were instructed to encourage their children (N = 65; ages 4–6) to explain, explore, or engage as usual. Instructions led to different patterns of play at the exhibit: Encouragement to explain led to greater discussion of gear mechanisms, whereas encouragement to explore led to more time connecting gears. In the explain condition, parents' questions predicted their children's discussion and further testing of gears. Questions also predicted the amount of time children spent on a follow-up task. Parents' exploration predicted an increase in exploration by their children. These data indicate that minimal interventions impact parent–child interaction at a museum exhibit and that prompts to explore or explain uniquely influence parent and child behavior.

Children's causal knowledge develops in everyday social contexts, often in collaboration with parents (Benjamin, Haden, & Wilkerson, 2010; Crowley et al., 2001; Nolan-Reyes, Callanan, & Haigh, 2016; Schulz, Bonawitz, & Griffiths, 2007; Sobel & Sommerville, 2010; Weisberg, Hirsh-Pasek, & Golinkoff, 2013). Despite the widespread recognition that children learn through collaboration, most research on children's causal reasoning is conducted on individual children in laboratory settings (for critiques see Bjorklund, Hubertz, & Reubens, 2004; Callanan & Valle, 2008; Fender & Crowley, 2007; Kline, 2015; Legare, Sobel, & Callanan, 2017). The objective of this study was to examine the social context of children's causal learning by studying exploration and explanation during parent–child interaction in a real-world learning environment: a children's museum. We define *exploration* as the process by which individuals act on the world in ways that generate information from others or the environment. We define *explanation* as the verbal information individuals generate about causal mechanisms, causal relations, and underlying causal principles that govern those relations (Legare et al., 2017).

Explanation and Exploration Work in Tandem

Within the causal learning literature, explanation and exploration are often described as independent

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and often divergent processes with different results on learning outcomes. For example, Klahr and Nigam (2004) showed that, compared to self-directed exploratory learning, direct instruction (i.e., generating explanations) was more effective in helping fourth-graders learn about scientific methods and make broader scientific judgments. In contrast, Bonawitz et al. (2011) describe a "double-edged sword" for the effect explanations have on exploration; causal information generated by a teacher in a pedagogical context may reduce children's exploration and what they potentially discover about an object. Directly explaining an outcome may give children the impression that there is nothing else to learn or discover. This may allow for rapid learning of information but may also reduce the tendency for children to seek out further information through hands-on experience.

From a young age, children are motivated to explore ambiguous or confounded outcomes (Gweon & Schulz, 2011; Gweon, Tenenbaum, & Schulz, 2010; Legare, 2012; Schulz & Bonawitz, 2007; Stahl & Feigenson, 2015). Between 4 and 7 years old, children's exploration becomes more systematic; they act to uncover new information or fill in gaps in their knowledge (Cook, Goodman, & Schulz, 2011; Gweon, Pelton, Konopka, & Schulz, 2014; Kushnir, Wellman, & Gelman, 2009; Sobel & Letourneau, 2017).

Preschoolers also reveal causal knowledge through their explanations (Schult & Wellman, 1997; Sobel, 2004), often before they can use causal knowledge to make accurate predictions (Bartsch & Wellman, 1989; Legare, Wellman, & Gelman, 2009; Wellman & Liu, 2007). Generating their own explanations can help children interpret data (Bonawitz, van Schijndel, Friel, & Schulz, 2012), apply knowledge to novel situations or circumstances (Legare & Lombrozo, 2014; Walker, Lombrozo, Legare, & Gopnik, 2014), and learn to make novel inferences (Amsterlaw & Wellman, 2006; Chi, de Leeuw, Chiu, & LaVancher, 1994; Crowley & Siegler, 1999; Legare, Gelman, & Wellman, 2010; Macris & Sobel, 2017; Rittle-Johnson, Saylor, & Swygert, 2008). Children also solicit causal explanations from others early in development by asking questions (Callanan & Oakes, 1992; Chouinard, 2007; Frazier, Gelman, & Wellman, 2009).

In sum, there is substantial evidence that exploration and explanation interact to drive children's causal learning. Children explore when their understanding is uncertain or when they register their own ignorance and generate explanations to synthesize the data they observe from that exploration. They learn from others' explanations while also treating others' explanations as opportunities to engage in (or not engage in) other kinds of exploration.

In this study, we examined the interplay of exploration and explanation during parent–child interaction at a children's museum exhibit following an instructional intervention that encouraged exploration or explanation. By manipulating the instructions given to parents to focus children on exploration or explanation, we investigated the extent to which parents' behavior changed, whether that change in behavior affected children's behavior, and whether behaviors generated by parents and children resulted in different types of learning. The answers to these questions not only contribute to our understanding of the development of causal reasoning but also provide useful information to museum practitioners, who seek to create supportive educational settings for children's learning (Borun, Chambers, Dritsas, & Johnson, 1997; Gutwill & Allen, 2010).

Parent–Child Interaction in Informal Learning Environments

Exploration and explanation are frequently examined independently of each other in psychological research, yet in real-world learning environments, they often operate concurrently, especially during everyday social interactions. This may be an effective way for children to learn. Mayer (2004), for example, argues for the benefits of structured play, in which adults and peers guide children's exploration and use it as a platform for explanations. Such an environment is seen as superior to both unstructured play and direct instruction to promote learning. These ideas were initially conceptualized as part of formal education environments but can also be applied to informal learning environments.

Children's museums and science centers are particularly fertile environments for studying both collaborative and individual learning. They are designed to foster both child-directed exploration and parent–child interaction. The Association for Children's Museums advocates museums as "places where all families are welcome and learn together through play and hands-on activity" (ACM, 2015, p. 11; National Research Council, 2009). In partnership with a science-focused children's museum, we studied the interaction of families' exploring and explaining, and the impact of that interaction on children's causal learning. In particular, we examined how interaction at a gears exhibit facilitated understanding of gears and both problem solving and troubleshooting behaviors during play, which are central to scientific thinking.

Several strategies successfully promote parent–child explanations in museum contexts. Benjamin et al. (2010), for example, showed that parents' explanatory behaviors at an engineering exhibit varied depending on the previsit instructions they were provided (see also Haden et al., 2014). Both conversational instruction (i.e., encouraging the use of *wh*-questions) and content-based instruction (i.e., providing information about a key engineering principle relevant to the exhibit) increased parents' elaborative STEM-related talk. Gutwill and Allen (2010) found that facilitated activities in which families developed their own "juicy questions" about exhibits—questions that no one knows the answer to and that can be answered by interacting with the exhibit—led to deeper inquiry later. Fender and Crowley (2007) showed that children who heard explanations about an exhibit were more likely to have a deeper conceptual understanding of the exhibit content and mechanism. Museum-based interventions in the form of additional signage or questions can impact how people interact with museum exhibits (e.g., Atkins, Velez, Goudy, & Dunbar, 2009; Gutwill, 2006). Finally, conversation cards designed to facilitate elaborative talk promoted such talk between parents and children, and improved subsequent memory transfer by children for the information presented in the exhibit (Jant, Haden, Uttal, & Babcock, 2014).

Conversation card interventions—specifically instructing parents to interact with children around particular constructs related to the exhibit—are effective at changing explanatory behavior (Benjamin et al., 2010), yet little is known about the impact of conversation cards on parent–child exploratory behavior and how parent–child explanatory and exploratory behavior interact. In the current study we examined the extent to which a minimal conversation card intervention can influence the frequency with which parents encourage their children to explore or explain and whether conversation card interventions or the kind of behavior parents and children engage in during their interaction at the exhibit relates to independent measures of children's causal learning and free play behavior used in previous research (Legare & Lombrozo, 2014).

Current Study

Gears and gear exhibits provide an informative context for examining children's causal learning. They are straightforward to manipulate, and the actions and consequences of gears are entirely visible, yet fully understanding the mechanism requires the understanding of scientific principles such as torque, mechanical advantage, and the transfer of motion. Previous research on gears has focused largely on children's understanding of the transfer of motion and has used explicit follow-up questions to assess knowledge of gear mechanisms (e.g., Lehrer & Schauble, 1998; Metz, 1985). Preschool-aged children can understand the causal mechanisms behind transfer of motion (e.g., Bullock, Gelman, & Baillargeon, 1982), and an explicit understanding of these causal systems develops between 7- and 11-years of age (see also Dixon & Bangert, 2002).

Legare and Lombrozo (2014) examined the impact of explanation on the understanding of the causal mechanism of gears in younger children (4- to 6-year-olds). They found that when children in this age group were prompted to explain how a gear machine worked they had a better subsequent understanding of certain facets of the causal mechanisms of gears and could better reconstruct a gear machine they previously observed. Additionally, children whose undirected responses contained causal explanations more readily generalized causal understanding to a novel gear task.

Here we build upon this research by examining how explanation together with exploration can be promoted in real-world learning settings. We also studied whether the behaviors observed in a naturalistic setting have a similar impact on causal understanding as those elicited in a lab. Thus, the objectives of this study were to examine: (a) whether and how parent–child interaction is influenced by an instructional intervention asking parents to encourage their children to explore or explain a gear exhibit, (b) how parents' behavior affects the way their children engage with the gear exhibit, particularly when parents are primed to have their children engage in exploration or explanation, and (c) whether children's ability to understand and recreate novel gear machines on their own is predicted by their previous interactions with their parent in a gear exhibit.

First we asked families to engage with a gear exhibit on the floor of a children's museum. Next, we presented children with a series of four follow-up tasks (i.e., memory, mechanism, reconstruction, and generalization tasks), which took place in a quiet room off the museum floor. These follow-up tasks included a novel set of gear stimuli (see Legare & Lombrozo, 2014). Prior to their interaction with the exhibit, researchers read parents one of three different conversation cards (see Gutwill & Allen, 2010), which prompted them to either encourage their children to explore the exhibit, or to explain facets of the exhibit, or encouraged parents to interact as they typically would in a museum exhibit. Through this manipulation, we seeded how parents were to interact with their children and what sorts of behaviors they should encourage at the exhibit to examine whether cues to encourage children's exploration or explanation would influence what parents and children would do during the free play.

For our first objective, we compared the impact of instructions that focused parents on encouraging explanation, encouraging exploration, or baseline interaction on behavior in the exhibit. This allowed us to assess the impact our manipulation had on explanation and exploration at the exhibit. We predicted that instructions given to parents to encourage explanations from children would show increased behaviors that accomplished this goal (such as question-asking and question-answering behaviors). When instructed to have children explore, we predicted that parents would encourage children to engage more with the exhibit materials and connect more gears. We also examined how children's interaction with the exhibit changed over the course of a 3-min interaction and how this was affected by instructions given to parents.

For our second objective, we planned in-depth exploration of the interaction between parents and children at the exhibit. We examined the free play session via a time-series analysis, treating the amount and nature of exploration with the materials as within-subject variables over time. This allowed us to examine how children explored and explained throughout the session, whether the frequency of these behaviors changed over time, and whether there were differences in those frequencies based on the conversation card their parents received. This also allowed us to assess if the conversation cards impacted more than just the amount of time children engage in different behaviors, but also when in the interaction they engaged in each type of action.

We also examined the relations between parent and child behaviors at the exhibit by exploring how parents' behavior, explanatory questions, and encouragement at one time interval predicted their children's behaviors in the subsequent time interval. This gives us an estimate of how parents' behavior influences their child's behavior. The analysis of parents' behavior predicting children's subsequent behavior was also exploratory. This allowed us to test whether parents' explanatory questions predicted children's subsequent discussion of the gears or children's further engagement in exploration or both, and if the impact of parents' questions differed from the impact of parents' exploration on their children's engagement with the exhibit.

For our third objective, we examined how child and parent behavior related to children's performance on independent measures of causal reasoning as a way of assessing if exhibit behavior was related to differences in causal reasoning. Given the exploratory nature of our analyses of the dynamics between exploration and explanation during parent–child interaction, examining differences in explanatory and exploratory behavior related to scores on the follow-up measures were also exploratory in nature.

Method

Participants

Sixty-five parent–child dyads participated. Children ranged in age from 4- to 6-years-old (M = 5.06 years, or 67 months); 30 of the children were female. This age range was chosen based on previous research on children's reasoning about gears (Legare & Lombrozo, 2014) and because it is the age at which most children interacted with the gear exhibit at the museum. Parents' reported ethnicity of their family was as follows: 47 white (non-Hispanic), 7 Hispanic, 4 Asian, 1 African American, and 6 mixed ethnicity. Parents were mostly female (44), with an average age of 36 years. Sample size was constrained by the number of participants we were able to collect data from during the summer period in which the museum allowed us access to the exhibit. Twenty additional dyads were recruited but did not complete the experiment and thus where not included in the analysis (9 did not complete the study, 11 were dropped for because of errors in video such that either the exhibit or outcome was not fully recorded or a majority of activity was not visible on the camera).

Museum Demographics

Data were collected between April and September 2013 at the Austin Children's Museum. Based on museum visitor surveys, visitors to the museum were 62% white (non-Hispanic), 13% Hispanic, 4% Asian, 4% African American, 4% mixed ethnicity, with 11% not responding. Child visitors typically ranged between 1 and 6 years of age. The median household income was between $80,000–$99,000, and 84% of the visitors resided in the city of Austin, TX.

Figure 1. Gear exhibit set up. [Color figure can be viewed at wileyonlinelibrary.com]

Materials

The gear exhibit at which parents and children interacted for the free play session is depicted in Figure 1. Fifteen gears were placed unconnected on the table, with additional gears available nearby if needed. The wall above the exhibit featured gears that the dyads could turn but not reconfigure (interaction with these gears was not included in the coding described below as it was not clearly visible on the video recordings).

During the follow-up measures, children were shown a set of gears from the Gears! Gears! Gears! Toy, a commercially available set of toy gears. The gears used in these measures are shown in Figures 2a–2e.

Table 1
Conversation Card Conditions

Common text across conditions	Welcome to the gear exhibit! Gears come in many different sizes and colors. They can be used to make many different kinds of machines.
Baseline	We are interested in how parents and children spend time together at the exhibits. We would like to learn more about families visiting the exhibits at the museum. Please interact with your child as you normally would.
Encouraging explanation (explain)	While your child is interacting with the gears, try asking them to explain how the gears work. Ask them to tell you about the gears or to describe what happens when they interact with the gears in different ways. Ask them questions about how the gears work or what will happen when a gear moves. Encourage them to think aloud about how the gears work.
Encouraging exploration (explore)	While your child is interacting with the gears, try encouraging them to explore how the gears work. Ask them to try new things with the gears. Urge them to interact with the gears in different ways. Suggest that they figure out how the gears work, or what will happen when a gear moves. Encourage them to experiment with how the gears work.

Procedure

Parent–child dyads were recruited at the museum and invited to play with the gear exhibit for 3 min. This interaction was videotaped. At the start of each session, dyads were randomly assigned to one of three conditions, *baseline, encouraging explanation*

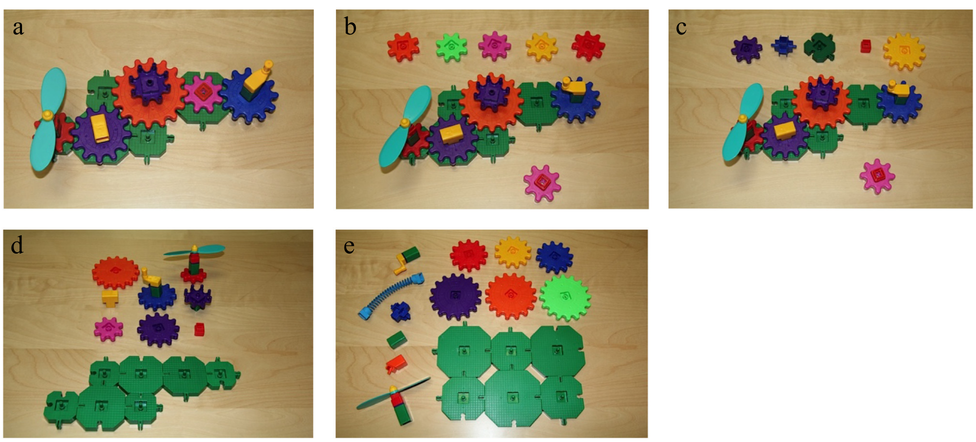

Figure 2. Follow-up gear machine task. (a) Gear machine used for experimental task; (b) memory learning task stimuli; (c) mechanism learning task stimuli; (d) reconstruction task stimuli; (e) generalization task stimuli. [Color figure can be viewed at wileyonlinelibrary.com]

(explain), and *encouraging exploration* (explore), in which parents were given a conversation card with instructions for their interaction (see Table 1 for wording of the instructions). In the *baseline* condition, parents were prompted to interact with their child at the gear exhibit as they normally would. In the *encouraging explanation* (explain) condition, parents were prompted to ask questions as a way of encouraging their children to explain the gear mechanism. In the *encouraging exploration* (explore) condition, parents were told to encourage their children to explore how the gears worked and get them to try new things. The area around the table was roped off to discourage other museum guests from interfering with the experiment. This was successful most of the time. All parent and child behavior and speech from these interactions was later coded for analysis from the videotapes.

After each parent interacted with their child at the gear exhibit for 3 min, the child was taken to a separate room to complete the follow-up tasks. Children completed a set of four tasks designed to assess their memory, understanding of gear mechanisms, and free play behavior when acting independently of their parent (see Legare & Lombrozo, 2014). During the follow-up tasks parents completed a short demographics form.

The follow-up tasks began with the experimenter showing children a novel gear machine and demonstrating how it worked (see Figure 2a). The first of the four follow-up tasks was designed to assess children's *memory* for the perceptual features of the gears: The experimenter removed a single gear out of sight of the child and then showed children the incomplete machine along with a set different colored gears of the same size as the missing gear. Children were asked "Which gear will make it look like it did before?" (see Figure 2b). This memory task was included primarily as a control. The second follow-up task was designed to assess children's understanding of *mechanism* or causal understanding: The experimenter removed a different gear from the machine, out of sight of the child, and then showed them a set of different gear and nongear parts, only one of which could be used to make the gear machine functional again. Children were asked "Which gear will make it work like it did before?" (see Figure 2c). For both the memory task and the mechanism task, if children did not answer correctly on the first try, they were told their answer was incorrect and given a second chance to answer. This second task was designed to assess children's understanding of the basic causal mechanism involved in connecting gears.

The third follow-up task was a *reconstruction* task. The gear machine was taken apart completely, out of sight of the child. Children were asked to put it back together so it would work the same way it did before. They were given 4 min to do so (see Figure 2d). This was included as a more difficult task to assess children's more complex mechanism understanding. The final follow-up task was a *generalization* task: Children were given a novel set of gears and a new base, and they were given 4 min to build a new machine (see Figure 2e). This last task was designed to assess children's causal affordances of the gears, as well as how they engaged in free play behaviors independent of parent input.

Coding

Exploration During Free Play at Exhibit

Parent and child behavior were coded separately, where each behavior was coded as an individual event using Datavyu software. The entirety of the 3-min parent–child interaction was coded (range = 2.9–3.8 min; M = 3.3 min), beginning with the parent's or child's first action on the exhibit and ending when the child stopped interacting with the exhibit. Relevant behaviors during the exhibit interaction were categorized into mutually exclusive types (i.e., "spinning a single gear," "connecting a gear to two or more already connected gears," etc.; see Table 2). Spinning and connecting behavior were split up into multiple categories based on complexity so we could look at the change in complexity of behavior over time.

Coders noted the start and end of each behavior. These events were converted into 1-s time steps (i.e., if children spun a single gear for 5 s, they would have five time steps of the code "spun a single gear"). For each 1-s segment, parents' and children's behaviors were coded into the categories shown in Table 2. These behaviors included cases in which parents or children were not interacting with materials on the gear table, interacting with only one gear, connecting gears to one another, spinning gears, or trying to fix gears that had been connected but came apart (labeled *troubleshooting*). Scaffolding behaviors included parents helping children by offering them gears. In Table 2, we separate different types of spinning and connecting behaviors, but for most of our analyses, these are combined.

Reliability between coders was calculated across the 1-s time steps on 23% of the videos (15 of 65 videos; parent κ = .87; child κ = .86). Once reliable,

Table 2
Exploration Coding: Mean Number of Seconds for Caregivers' and Children's Exploratory Behavior in Each Coding Category

	Child	Parent
Behavior		
Not interacting with table: Not touching or otherwise playing with the table or gears.	42.03	145.52
Exploring materials: playing with the gears or table but not connecting or spinning.	15.60	7.69
Spinning a single gear: spinning a gear that is not connected to any other gears.	21.46	2.49
Spinning two connected gears[a]*:* Spinning a machine made up of only two gears.	4.11	0.60
Spinning more than two connected gears[a]*:* spinning a machine made up of more than two gears.	35.32	2.91
Connecting two gears[b]*:* attaching a gear to a single other gear not attached to any other gears.	12.57	2.14
Connecting a gear to two or more connected gears[b]*:* adding gears to a machine that contains at least two already connected gears.	46.15	8.12
Attempting but not succeeding to spin connected gears: trying to turn gears that do not spin because they are locked or have drifted apart while attempting to spin (usually because of child accidently moving one of the gears).	11.98	1.37
Troubleshooting: fixing gear machines that are locked and would not spin by moving gears; pushing gears that have drifted apart back together	9.35	3.85
Scaffolding behavior		
Parent correcting child's actions[c]*:* helping child connect gears by showing; giving them a different size gear when one won't fit.	—	15.05
Parent directing attention[c]*:* pointing at any part of the table or gears.	—	8.54

[a]These codes were combined into a single category of "spinning" for all analyses except the time-series analysis. [b]These codes were combined into a single category of "connecting" for all analyses except the time-series analysis. [c]These codes were combined into a single category of "scaffolding." Total time of interaction was approximately 3-min for all participants.

two independent coders each coded approximately half of the videos each.

Parents' and Children's Language During Free Play

All verbal data from the exhibit interaction were transcribed and coded. Each utterance generated by parents and by children was coded into mutually exclusive categories, described in Table 3. Our coding scheme focused on (a) causal questions generated by each speaker (explanatory questions), (b) talk about the exhibit (machine talk), (c) praise or encouragement on the part of the parent (encouragement), (d) directives on the part of the parent (imperatives), and (e) other noncausal language that was irrelevant (appearance). This allows us to examine how parents and their children discussed the exhibit through questions and other conversation about gears, as well as how parents encourage or direct their children. We look at the potential positive and negative results of each. These categories, with the exception of appearance, were included because of relevance to our objectives. Appearance was added to help clarify the coding scheme for our coders.

Utterances were parsed into single concept statements before coding (see examples in Table 3) and coded into mutually exclusive categories. If two codes were possible, preference was given to explanatory questions and machine talk in the order codes are listed in Table 3 (i.e., if something could be coded as both machine talk and imperative, preference was given to machine talk). Reliability was calculated on statements for 23% of the videos (15 of 65 videos; $\kappa = .81$). Once reliable, two independent coders coded approximately half of the videos. Unlike behavior, reliability for verbal data was calculated on code agreement for individual statements rather than time. This was done to avoid inflating reliability with coder agreements on time spent not talking. Verbal data were then combined with the video coding using Datavyu (New York, USA). The beginning and end time of each utterance and the code was recorded.

Follow-Up Causal Reasoning and Play Measures

For the memory and mechanism selection tasks (in which children chose which gear would make the machine look/work the way it did before), children were scored on whether they picked the correct or incorrect gear.

For the reconstruction task, children were given a score between 0 and 5. Children received 1 point each for placing the three middle gears correctly on the base, 1 point for placing the handle in the right place, and 1 point for placing the fan in the right place. Children received a score of 0 if they did none of these things. A similar score between 0 and 8 was given for the generalization task. Children were given one point for each gear that was connected to another gear, and a point each for using the handle and using the fan. Points were given for the last two only if they were attached to a gear

Table 3
Utterance Coding: Mean Number of Seconds Spent Talking by Parents and Children for Each Coding Category

	Parent	Child	Examples
Explanatory questions: questions asking for an explanation or elicit an explanation.	25.54	0.42	"And why is it spinning?" "Okay, so what's the difference between this one that's moving and this one that's moving?"
Machine talk: talk about gears, handle, connecting or spinning.	8.02	3.52	"They're put together. See? And one moves and the other pushes." "Any one with a handle right? You can spin it around because they're all connected."
Encouragement: (parents only) statement of encouragement	5.23	—	"Oh, wow. Ok great." "Nice!"
Imperative: (parents only) telling child to do something.	8.80	—	"Now move it where you want it to go" "Put 'em all together"
Appearance: color or shape	1.88	1.40	"Here's a pink one." "Look at how little this one is"
Other talk: any other talk	18.83	11.12	

Note. Total time of interaction was approximately 3-min for all participants.

and the gear was attached to the machine base. We also measured the amount of time children spent on the generalization task, from the time the gears were given to children to the time children said they were finished, or until 4 min was up, whichever came first.

Results

Our results are divided into three sections. In the first section, we analyzed the impact of the conversation cards on parents' and children's behavior at the exhibit. This is done in two ways. First, we examined if the conversation card prompts impacted the amount of time parents and children spend on each coded explanation and exploration behavior. Second, we looked at changes in the complexity of children's exploration behavior over the course of the interaction using a time-series analysis. By looking at different levels of complexity in exploration behavior over time, we create a picture of how children engaged in building and spinning behaviors at different points in the interaction and how changes in behavior over the course of the interaction were impacted by the conversation card prompts.

In the second section, we engaged in exploratory analyses to look at how parents' behavior impacted their children's behavior during the exhibit interaction. We do this using what parents were doing in the previous 10-s to predict children's behavior in the next 10-s. This allows us to examine if parents' exploration, explanatory questions, or encouragement impacted the types of behaviors that their children engaged in the next 10-s, and gives us some indication of how parents' behaviors might change their children's explanation and exploration.

In the final section, we examined whether the conversation card prompts or parents' and children's behavior during the exhibit interaction phase predicted children's performance on the follow-up tasks. On the basis of previous findings, we expected the explanation condition to increase children's understanding of the gear mechanism more than the exploration condition (Legare & Lombrozo, 2014). To look at the impact of behavior on the follow-up tasks, we used the amount of time parents and children spent in each behavior to predict children's scores on the follow-up tasks. Though these analyses were planned, they should still be treated as exploratory as we had no strong prediction about which behaviors would affect each outcome task.

Impact of Conversation Cards on Behavior

We examined whether condition prompts influenced parent and child behaviors. Raw averages are presented in Table 4. In this table both connecting and spinning are a combination of two coded categories defined in Table 2. *Connecting* represents the total amount of time spent engaged in either connecting one gear to one other gear or connecting one gear to two or more gears; *spinning* represents the total amount of time spent spinning two or more connected gears.

Effects were assessed using regression models with behavior as the dependent variable and condition as the predictor. Condition was dummy coded

Table 4
Average Time, in Seconds, Spent by Parents and Children for Each Category of Exploration and Explanation in the 3-Min Videotaped Interaction

	Baseline	Explain	Explore
Child			
Connecting	56.00	36.75	82.55
Spinning	32.33	50.13	34.05
Troubleshooting	9.71	7.70	10.30
Machine talk	0.88	6.50	1.00
Questions	0.33	0.66	0.25
Parent			
Connecting	12.48	7.79	10.90
Spinning	3.57	1.83	5.45
Troubleshooting	5.32	1.54	5.15
Scaffolding	3.11	2.88	2.49
Machine talk	7.61	7.50	9.50
Questions	20.14	38.33	15.85
Imperative	8.29	9.96	7.95
Encouragement	4.85	4.83	6.10

so that both explain and explore conditions were compared to the baseline condition. Children's age, gender, and the total time they spent in the exhibit were included as control variables. Age was considered in terms of years, with months converted to decimals. The results of the analysis are presented in Tables 5 and 6.

In Tables 5 and 6, the coefficients for condition can be interpreted as the average time difference (in 10-s increments) between the explain or the explore condition and the baseline condition. Significance is supported by bootstrapped 95% confidence intervals (10,000 iterations) due to some non-normality in the residuals. Children engaged in a variety of behaviors throughout the interactions and switched between behaviors such as spinning and connecting frequently. Differences presented can be interpreted as differences in relative frequencies of each behavior.

The explain condition significantly impacted both parents' and children's behavior at the exhibit. In the explain condition, parents' troubleshooting behavior occurred for 3.9 s less on average than in the baseline condition, and parents generated an average of 18 more seconds of explanatory questions in the explain than in the baseline condition (see Table 5). Children's spinning behavior in the explain condition was greater than baseline by an average of 16.7 s, and their machine talk was greater than baseline by an average of 5.7 s (see Table 6). The amount of time children spent connecting gears in the explain condition was lower by an average of 19.2 s than the baseline condition. Parents' behaviors did not differ between the explore condition and the baseline condition. Children in the explore condition spent more time connecting gears by an average of 26.8 s compared to the baseline condition.

Impact of Conversation Cards on Behavioral Complexity Over Time

To look at the impact of conversation cards on exploratory behavior more closely, we examined

Table 5
Differences in Parents' Behavior Across Conditions Controlling for Child's Age and Gender

	Parent connect *B* (*SE*) [95% CI]	Parent spin *B* (*SE*) [95% CI]	Parent troubleshoot *B* (*SE*) [95% CI]	Parent scaffold *B* (*SE*) [95% CI]
Child age	.36 (.27) [−.05, .91]	.12 (.11) [−.05, .45]	−.09 (.10) [−.28, .10]	−.81 (.40)* [−1.62, −.14]
Gender (male)	−.24 (.42) [−1.04, .52]	−.01 (.16) [−.54, .25]	−.16 (.15) [−.48, .16]	.07 (.62) [−1.01, 1.49]
Explain condition	−.59 (.48) [−1.74, .33]	−.22 (.19) [−.51, .03]	−.39 (.18)* [−.77, −.09]	−.38 (.71) [−2.25, .88]
Explore condition	−.40 (.52) [−1.60, .71]	.10 (.20) [−.21, .59]	−.01 (.19) [−.44, .42]	−.54 (.75) [−2.25, .57]
Total time	−.24 (.16) [−.52, .01]	−.09 (.06) [−.23, .02]	−.02 (.06) [−.11, .10]	−.20 (.23) [−.54, .31]
	Parent machine talk	**Parent questions**	**Parent imperative**	**Parent encouragement**
Child age	−.05 (.14) [−.26, .19]	−.12 (.29) [−.67, .48]	.02 (.17) [−.38, .38]	.01 (.10) [−.16, .21)
Gender (male)	−.16 (.22) [−.63, .24]	−.24 (.44) [−1.01, .58]	−.18 (.26) [−.7, .26]	−.20 (.15) [−.49, .05]
Explain condition	−.08 (.24) [−.67, .38]	1.80 (.52)*** [.61, 2.86]	.22 (.29) [−.37, .86]	−.03 (.17) [−.32, .29]
Explore condition	.08 (.26) [−.56, .65]	−.42 (.54) [−1.53, .35]	.004 (.31) [−.57, .47]	.09 (.18) [−.25, .45]
Total time	−.11 (.08) [−.23, .03]	−.01 (.17) [−.35, .26]	.09 (.09) [−.09, .23]	−.03 (.05) [−.13, .04]

Note. N = 65. Betas are in 10-s intervals.
$^{*}p < .05$. $^{***}p < .001$.

Table 6
Differences in Children's Behavior Across Conditions Controlling for Age and Gender

	Child connect		Child spin		Child troubleshoot	
	B (*SE*)	[95% CI]	*B* (*SE*)	[95% CI]	*B* (*SE*)	[95% CI]
Child age	−.11 (.50)	[−1.08, .79]	.25 (.41)	[−.73, 1.00]	.12 (.18)	[−.24, .46]
Gender (male)	−.25 (.76)	[−1.65, .97]	−.52 (.63)	[−1.75, .86]	.07 (.27)	[−.41, .59]
Explain condition	−1.92 (.87)*	[−3.49, −.19]	1.67 (.72)*	[.21, 3.15]	−.22 (.31)	[−.89, .38]
Explore condition	2.68 (.92)**	[.46, 4.66]	−.31 (.77)	[−1.37, 1.44]	.01 (.33)	[−.67, .69]
Total time	.02 (.28)	[−.74, .64]	−.40 (.23)†	[−.87, .02]	−.05 (.10)	[−.22, .19]

	Child machine talk		Child questions[a]	
Child age	.01 (.10)	[−.14, .16]	.02 (.02)	[−.02, .12]
Gender (male)	−.13 (.15)	[−.49, .07]	.05 (.03)	[.01, .12]
Explain condition	.53 (.17)**	[.24, 1.07]	.03 (.04)	[−.04, .13]
Explore condition	.01 (.18)	[−.11, .16]	−.01 (.04)	[−.09, .04]
Total time	.001 (.05)	[−.07, .20]	.01 (.01)	[−.02, .02]

Note. $N = 65$. Betas are in 10-s intervals.
[a]These data are highly zero inflated.
†$p < .10$. *$p < .05$. **$p < .01$.

how condition impacted changes in the complexity of children's behavior during the exhibit interaction over time. To look at this behavioral change, we created dependent variables by combining behavior codes into scales for spinning (0 = not spinning; 1 = spinning a single gear; 2 = spinning two connected gears; 3 = spinning more than two connected gears) and material exploration (0 = not exploring materials; 1 = exploring materials/messing around; 2 = connecting a gear to another gear; 3 = connecting a gear to two or more connected gears).

These scales were used as dependent variables with time in 1-s intervals as a predictor. Because the dependent variables are ordinal, these models were run as multilevel ordinal regressions (cumulative link models) with conditions included as a predictor (Table 7). The resulting effects for both spinning and material exploration behavior over time were nonlinear, so we added a time-squared coefficient to the models to allow for a curve in the effect over time (i.e., the slope of behavior is not consistent; time spent on complex behaviors increases at the beginning of the interaction, but then declines again toward the end; see Figure 3). Time was centered individually at the midpoint of each dyad's exhibit interaction to remove collinearity between the time and time-squared coefficients. Multilevel models with random slopes (time and time-squared) and intercepts (midpoint) for each child were used to predict the complexity of children's behavior across the interaction (Table 7).

Table 7
Ordinal Multilevel Model of Children's Material Exploration and Gear Spinning Behavior Across Time

	Material exploration		Spinning	
	B (*SE*)	Odds	*B* (*SE*)	Odds
Time	0.24 (0.22)	1.28	0.24 (0.15)	1.27
Time^2	−2.52 (0.34)***	0.08	−0.72 (0.24)**	0.49
Age	0.17 (0.20)	1.18	−0.06 (0.12)	0.94
Gender (M)	−0.32 (0.29)	0.73	0.06 (0.18)	1.06
Explain condition	−0.76 (0.34)*	0.46	0.55 (0.20)**	1.73
Explore condition	0.78 (0.37)*	2.18	−0.14 (0.22)	0.87
Threshold coefficients				
0|1	0.82 (1.05)	2.27	1.00 (0.19)	2.71
1|2	1.29 (1.05)	3.63	1.67 (0.19)	5.31
2|3	1.73 (1.05)	5.64	1.83 (0.19)	6.23

Note. Time steps are 1-s intervals.
**$p < .01$. ***$p < .001$.

Figure 3 shows the probability of engaging in each type of behavior over time for each of the three conditions. The solid lined for both material exploration (left) and spinning (right) represents the most complex behavior. From this, we can see that children in the explore condition were more likely to engage in more complex material exploration (building large machines by connecting multiple gears together; Figure 3e) than baseline condition. In the explain condition, children were no more likely to engage in complex material exploration than they were to explore the materials but not

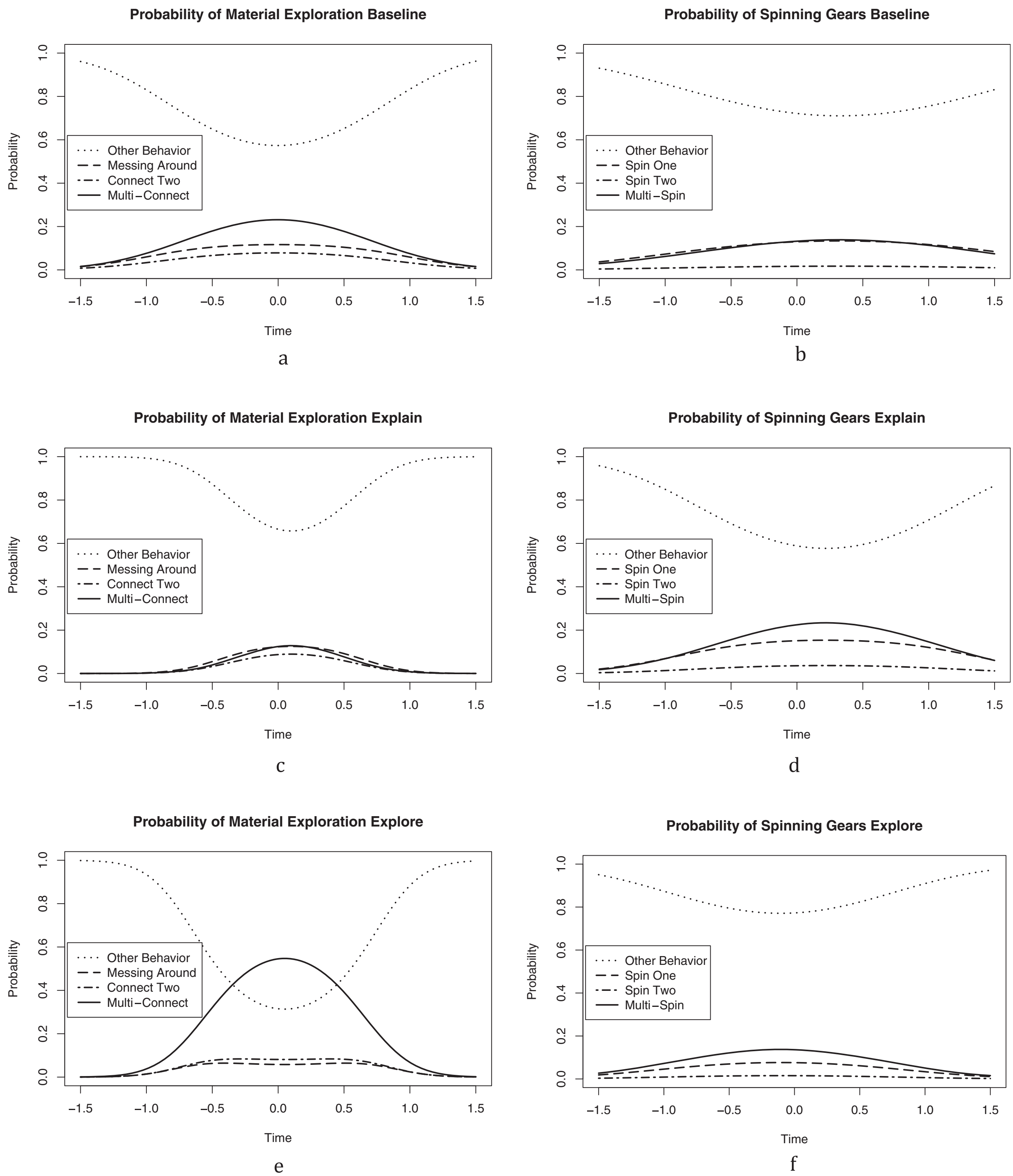

Figure 3. Average probability of engaging in each type of behavior in each condition over the 3-min interaction for material exploration behavior (a, c, e) and spinning behavior (b, d, f) by condition.

connect (messing around) at any point in the interaction. This can be seen in Figure 3c where the lines representing the probability of these behaviors almost completely overlap throughout the interaction. At the same time, children in the explain condition (Figure 3d) were more likely to spend time spinning the complex machines they did build than in the baseline condition (Figure 3b).

In all conditions, children engaged in complex connecting and spinning behavior in the middle of the interaction, and this declines again toward the end of the interaction (this is shown by the negative time-squared coefficient in Table 7 and the bell shaped probability curves in Figure 3). This decline at the end of the interaction is less for spinning than connecting, particularly in the explain condition (Figure 3d) and baseline conditions (Figure 3b). Children continue to spin the machines they have built after they stop building, sometimes right to the end of the interaction. This is most clearly seen by looking the probability of children engaging in any nonspinning behavior (at the dotted line at the top of the plots), which stays further below 1 than it does for material exploration.

Impacts of Parents' Behavior on Children's Behavior During Parent–Child Interaction

To look at how parents' behavior predicted how children interacted with the gear exhibit in each condition, we divided up each dyad's 3-min exhibit interaction into 10-s intervals and used parents' behavior from the previous 10-s to predict children's behavior in the 10-s that immediately followed. Our dependent variable was the number of seconds children engaged in a specific explanation or exploration behavior (i.e., spinning or connecting) during each 10-s interval. The predictor variables were the number of seconds parents engaged in a behavior in the 10-s interval immediately before the children's 10-s. This was done for the whole 3-min exhibit interaction. To illustrate the differences across condition, analysis was done in each condition separately. As in Tables 5 and 6, spinning included both spinning two attached gears and spinning multiple attached gears and connecting included connecting a gear to one other gear or too many other gears.

These data were analyzed using multilevel regression models. This allows us to run an analysis using multiple time points for each dyad that accounts for individual differences in initial behavior (random intercepts) but assumes similar impacts of parent behavior on their child's behavior for all dyads (fixed slopes). We chose to include only parents' building, spinning, and troubleshooting behavior, as well as explanatory questions and encouragement (Table 8). The first three are all relevant behavioral items related to exploration. Explanatory questions and encouragement are additionally relevant and potentially interesting ways of changing children's subsequent engagement and behavior.

Children's connecting behavior was predicted by parents' prior connecting behavior in the baseline condition and by parents' encouragement in the explain condition. In the baseline condition, when parents spent 10 s connecting, their children's

Table 8
Predicting Children's Behavior From Parent Past Behavior (in the Previous 10-s)

	Child connect *B* (*SE*) [95% CI]	Child spin *B* (*SE*) [95% CI]	Child troubleshoot *B* (*SE*) [95% CI]	Child machine talk *B* (*SE*) [95% CI]
Baseline				
Parent connect	.44 (.10)*** [.25, .63]	−.03 (.07) [−.17, .48]	.001 (.04) [−.08, .08]	
Parent spin	−.30 (.20) [−.68, .09]	−.04 (.14) [−.16, .11]	.06 (.09) [−.11, .24]	
Parent troubleshoot	−.27 (.16) [−.58, .04]	.16 (.11) [−.07, .38]	.17 (.07)* [.04, .31]	
Parent questions	.02 (.09) [−.16, .05]	.11 (.06) [−.02, .23]	.04 (.04) [−.04, .12]	
Parent encouragement	.19 (.26) [−.30, .70]	.94 (.19)*** [.58, 1.03]	−.02 (.12) [−.24, .21]	
Explain				
Parent connect	−.16 (.10) [−.36, .03]	.31 (.11)** [.10, .53]	−.04 (.05) [−.14, .05]	.01 (.03) [−.05, .08]
Parent spin	−.07 (.28) [−.64, .46]	.03 (.31) [−.57, .63]	−.07 (.14) [−.35, .20]	.06 (.10) [−.13, .24]
Parent troubleshoot	−.11 (.25) [−.60, .38]	−.09 (.27) [−.61, .44]	.10 (.13) [−.15, .34]	−.03 (.08) [−.19, .13]
Parent questions	−.09 (.06) [−.21, .03]	.18 (.09)** [.01, .31]	−.03 (.07) [−.09, .03]	.07 (.02)*** [.03, .11]
Parent encouragement	.46 (.14)** [.19, .74]	.01 (.15) [−.29, .32]	−.03 (.07) [−.17, .11]	.06 (.05) [−.04, .15]
Explore				
Parent connect	.01 (.11) [−.22, .24]	.03 (.08) [−.13, .18]	.16 (.05)** [.05, .26]	
Parent spin	.14 (.16) [−.18, .45]	−.05 (.11) [−.25, .18]	−.02 (.07) [−.17, .12]	
Parent troubleshoot	−.11 (.17) [−.44, .23]	.07 (.15) [−.16, .29]	.08 (.08) [−.07, .23]	
Parent questions	−.06 (.12) [−.30, .18]	.07 (.08) [−.09, .23]	.01 (.05) [−.09, .12]	
Parent encouragement	.20 (.20) [−.20, .59]	.34 (.14)* [.08, .61]	.04 (.09) [−.13, .22]	

Note. Additional controls not included in table: age and gender.
**p* < .05. ***p* < .01. ****p* < .001.

connecting behavior increased by 4.4 s in the next 10 s. In the explain condition, when parents spent 10 s encouraging, their children's connecting behavior increased by 4.6 s.

Children's spinning behavior was increased by encouragement in both the baseline, and exploration condition, but by parents' questions and connecting in the explain condition. Children's spinning behavior increased by 9.3 s in the baseline condition and by 3.4 s in the explore condition, when their parents spent the previous 10 s encouraging them. In the explain condition when parents spent 10 s asking question, their children's spinning behavior increased by 1.8 s, and when parents spent 10 s connecting, children's spinning behavior increased by 3.4 s. Children's troubleshooting behavior was impacted by parents' troubleshooting in the baseline condition, and by parents' connecting in the explore condition No significant effects were seen in the explain condition.

Only the explain condition was analyzed for children's machine talk because of the low base rate of this speech in the other two conditions. For each 10 s parents spend asking questions, children spent an additional 0.7 s talking about machines. Though this rate seems low, the base rate of machine talk is very low. In the explain condition, children only engage in this type of talk for an average of 0.4 s per 10 s in the explain condition, making this increase relatively large.

Although the number of observations is high, the sample of individual dyads in each condition is relatively small, thus some of these estimates are imprecise, as evidenced by the confidence interval in Table 8. A full analysis across all three conditions using all parent behaviors, and an analysis of concurrent behavior (what parents and children are doing at the same time) is included in Supporting Information.

Impact of Parent–Child Behavior on Follow-Up Causal Reasoning Tasks

To examine the impact of explanatory and exploratory behaviors on the follow-up tasks, we used time spent in each behavior as predictors with each follow-up task as a dependent variable. First, we analyzed results for the memory and mechanism task using binomial probit regressions. Because many of the predictor variables were zero inflated, probit models offered a better model fit than logistic regression. Scores were relatively high on the mechanism task, so only the first answers were analyzed for this task. Second, we analyzed results for the reconstruction task and children's score on the generalization task and persistence on the generalization task (i.e., time spent on generalization task) using linear regression. Due to concern over the ratio of predictors to sample size, coded explanations and exploratory variables were split into three models for each follow-up task (children's exploration behavior: spinning, connecting and troubleshooting; parents' exploration behavior: spinning, connecting and troubleshooting; and parents' explanations and scaffolding: explanatory questions, imperatives, encouragement, machine talk, and scaffolding behavior). Children's explanations were not included because of the infrequency with which they occurred. All models included controls for age, children's gender, and condition (see Supporting Information for complete regression tables). A breakdown by condition is presented in Table 9. No significant differences were found for condition on any of the outcome tasks; however, some parent behaviors did have a small impact.

Children that correctly answered the mechanism task also scored highly on the generalization task, $r = .42$, 95% CI [.20 to .60], but there was no significant relation with the reconstruction task, $r = .09$, 95% CI [−.15 to .32]. Scores on the reconstruction and generalization task were also related, $r = .27$, 95% CI [.02 to .48]. Correct answers on the memory tasks scores was related to generalization task scores, $r = .25$, 95% CI [.002 to .46] but not either of the other tasks (mechanism: $r = .12$, 95% CI [−.12 to .36]; reconstruction: $r = .20$, 95% CI [−.05 to .42]).

Analysis of the mechanism and memory task data showed that the more time children spent spinning gears the higher the probability that they

Table 9
Percent Correct or Average Score on All Follow-Up Tasks Across Conditions

Condition	Memory (first try), %	Memory (total), %	Mechanism (first try), %	Mechanism (total), %	Average reconstruction score	Average generalization score	Average time, min
Baseline	10	19	48	76	1.81	1.52	2.92
Explain	21	33	50	79	1.79	1.67	2.83
Explore	0	5	50	80	1.75	1.80	2.75

Table 10
Probit Regression Analyses of Explanatory and Exploratory Behavior Predicting Correct Answers on the Memory and Mechanism Tasks

	Memory (total)			Mechanism (first)		
	β (*SE*)	[95% CI]	Odds ratio	β (*SE*)	[95% CI]	Odds ratio
Child behavior						
Connecting	0.14 (.12)	[−0.09, 0.39]	1.15	0.07 (.07)	[−0.05, 0.21]	1.07
Spinning	0.24 (.11)*	[0.04, 0.47]	1.28	0.14 (.08)	[−0.01, 0.29]	1.14
Troubleshooting	0.61 (.25)**	[0.14, 1.14]	1.84	0.36 (.18)*	[0.03, 0.71]	1.43
Parent behavior						
Connecting	−0.19 (.20)	[−0.68, 0.17]	0.82	−0.09 (.12)	[−0.33, 0.14]	0.91
Spinning	0.03 (.44)	[−1.07, 0.84]	1.03	0.30 (.32)	[−0.28, 1.04]	1.35
Troubleshooting	−0.54 (.52)	[−1.76, 0.37]	0.58	0.54 (.31)	[−0.04, 1.13]	1.71
Parent scaffolding						
Questions	0.07 (.12)	[−0.17, 0.31]	1.07	−0.05 (.10)	[−0.25, 0.16]	0.96
Machine talk	0.02 (.28)	[−0.54, 0.55]	1.02	0.001 (.21)	[−0.40, 0.41]	1.00
Encourage	1.07 (.44)*	[0.25, 2.05]	2.92	0.17 (.32)	[−0.46, 0.81]	1.19
Imperatives	−0.20 (.24)	[−0.72, 0.27]	0.82	−0.30 (.19)	[−0.69, 0.06]	0.74
Scaffolding	0.01 (.10)	[−0.22, 0.19]	1.01	0.09 (.08)	[−0.05, 0.26]	1.10

Note. $N = 65$. Age, gender, condition, and total exhibit time are included as control variables in all regressions. Full table in Supporting Information. Probit was used rather than logit because of the zero inflation of these data.
$^{*}p < .05$. $^{**}p < 0.01$

would correctly answer the memory task (Table 10). Children's time troubleshooting gears predicted a higher probability of a correct answer on both the memory and mechanism. Parents' encouragement talk predicted correctly answering the memory task.

Next, we analyzed the reconstruction and generalization tasks. There were no effects of parent–child explanatory or exploratory behavior on children's scores on the reconstruction or generalization measures (Table 11). We also calculated the amount of time children spent on the generalization task. We did this as a metric of children's persistence with these stimuli. We added children's score on the generalization task as an additional control variable to the generalization-time analysis to eliminate

Table 11
Regression Analyses of Explanatory and Exploratory Behavior Predicting Correct Answers on the Reconstruction and Generalization Tasks

	Reconstruction		Generalization		Time spent (generalization)	
	β (*SE*)	[95% CI]	β (*SE*)	[95% CI]	β (*SE*)	[95% CI]
Child behavior						
Connect	.04 (.08)	[−.15, .20]	.12 (.13)	[−.11, .41]	−.29 (.15)	[−.55, .03]
Spin	−.003 (.09)	[−.17, .16]	.03 (.16)	[−.34, .35]	−.15 (.18)	[−.49, .20]
Troubleshoot	−.14 (.21)	[−.55, .30]	.36 (.37)	[−.37, 1.03]	.14 (.42)	[−.83, 1.00]
Parent behavior						
Connect	−.17 (.14)	[−.48, .17]	−.11 (.26)	[−.82, .51]	−.15 (.29)	[−.81, .52]
Spin	−.01 (.35)	[−.78, .88]	−.03 (.65)	[−1.61, 1.44]	.58 (.71)	[−1.51, 1.88]
Troubleshoot	−.33 (.37)	[−1.02, .52]	.42 (.68)	[−1.01, 1.84]	−1.62 (.74)*	[−3.53, −.07]
Parent scaffolding						
Questions	.04 (.13)	[−.25, .32]	.25 (.47)	[−.71, 1.24]	.53 (.26)*	[.05, 1.07]
Machine talk	−.14 (.26)	[−.64, .44]	.08 (.23)	[−.36, .55]	.76 (.52)	[−.11, 1.71]
Encourage	−.21 (.40)	[−.97, .72]	.81 (.71)	[−.59, 2.25]	.16 (.80)	[−1.37, 1.51]
Imperatives	.13 (.23)	[−.46, .64]	−.02 (.42)	[−1.02, .98]	−.20 (.46)	[−1.17. .83]
Scaffolding	−.17 (.09)	[−.34, .06]	.17 (.17)	[−.22, .52]	−.17 (.19)	[−.77, .11]

Note. $N = 65$. Age, gender, condition, and total exhibit time are included as control variables in all regressions. Score on generalization task was included as an additional control variable in persistence models. Full table in Supporting Information.
$^{*}p < .05$.

the possibility that the time spent on this task was simply a reflection of children's ability to build complex machines (i.e., children who had a better grasp of the mechanisms may have spent less or more time on the task).

Parents' troubleshooting behavior negatively predicted the amount of time children spent on the generalization task—each additional 10 s parents spent fixing the gears for their children in the exhibit predicted a decrease in 16.2 s in the time children spent on the generalization task. Parents' questions predicted an increase in children's persistence on the generalization task. For each additional 10 s parents spent asking questions, children spent an additional 5.3 s on the generalization task. The lack of differences by condition suggest that these effects may be driven in part by variation in parent behaviors generally, such as tendency to ask questions or troubleshoot for their children, rather than the behavior change created by the prompts to explain and explore. It is worth noting, however, that none of these effects remain significant when we correct for multiple comparisons across all possible predictors. Furthermore, because these analyses were largely exploratory they should be treated as preliminary and follow-up research needs to be done to determine reliability.

Discussion

We examined how parents and children interacted at a gear exhibit in a children's museum when they were instructed to encourage their children to explain, explore, or play as usual. We coded parent–child interaction and collected data on individual measures of children's causal learning. In relation to our three objectives, our results demonstrate that (a) parent–child interactions were influenced by an instructional intervention to parents, (b) parents' behavior affected the way their children engage with a gear exhibit, and found some evidence suggesting that (c) children's ability to understand and recreate novel gear machines on their own was predicted by their previous interactions with their parent in a gear exhibit.

For our first objective, we examined how simple instructions given to parents asking them to encourage their children to explain, or encourage their children to explore the materials and mechanism of gears, impacted how parents and children engaged with a museum gear exhibit. The conversation card manipulation impacted parent–child behavior in several ways. Encouraging children to explain versus explore revealed different patterns of behavior that, although divergent, were both potentially valuable for children's learning. When parents were encouraged to elicit explanations from their children, they spent more time asking questions and their children spent more time talking about gears. Encouraging explanations also affected how parents and their children explored the gear table. Children spent less time connecting gears and more time spinning gears in the explanation than the baseline condition. This suggests that children tested the gears more but in doing so perhaps spent less time building complex machines. These effects are also apparent in the time-series analysis where children in the explain condition were much less likely to connect to multiple other gears than in the explore condition but were more likely to spend time spinning the gears they had connected and to do so right until the end of the interaction. These results are similar to work suggesting potential tradeoff effects of pedagogy demonstrated by Bonawitz et al. (2011); children may see their parents as teaching them and therefore shift their focus onto what is being taught and away from what they can learn for themselves.

In contrast, in the exploration condition, when parents were asked to encourage their children to explore, children spent more time connecting the gears and building complex machines relative to the baseline condition, and were much more likely to engage in complex material exploration than in either other condition in the time-series analysis. In all conditions, material exploration peaked in the middle of the interaction and declined toward the end. The present work aligns with and extends other interventions using conversation cards (e.g., Gutwill & Allen, 2010; Jant et al., 2014). This previous work has focused mostly on how these interventions affect conversation at museum exhibits, with little focus on the specific of exploration behaviors. Additionally, this work extends similar findings about children's memory of their interaction with museum exhibits (e.g., Benjamin et al., 2010; Haden et al., 2014).

We found similar effects in our second objective, when we explored how parents' behavior impacted how their children explained or explored the gear exhibit. Parents used questions and encouragement to elicit different types of behaviors based on the cues they were given at the beginning of the interaction. Parents' questions preceded greater discussion of the gear machines by children in the explain condition, suggesting that these questions were eliciting discussion of the gears. Parents' explanatory questions also predicted an increase in the amount of time children subsequently spent spinning in the explain condition but not in the baseline or explore condition. This might have been due to the content or type of questions they were asking, but this information was not captured in our coding scheme. This effect offers some support for the possibility that children spun more in the explain condition to test hypotheses about how the machines worked and were encouraged to do so by their parents questions. Encouragement preceded an increase the rate of spinning in the explore and baseline conditions, and connecting more gears in the explain condition, suggesting that parents were using language differently to influence their child's behavior in different conditions.

Finally, for our third objective, we explored how the conversation and behavior during the exhibit interaction phase of the study was related to children's mechanism understanding in a series of four follow-up tasks. Despite the impact of prompting exploration or explanation on behavior during the exhibit play portion of the study, condition had no significant impact on outcome task performance. Exploratory analyses of children's behavior showed mixed relations—the follow-up measures only significantly predicting scores on the simple memory and mechanism questions but not the more complex reconstruction and generalization tasks, and the time children spent on the generalization task. The more time children spent troubleshooting while exploring the exhibit with their parent, the higher the probability that they correctly answered the memory and the simple mechanism questions. This suggests that children who encounter challenges and work to resolve them also have a better memory for perceptual features of gears and a better grasp of gear mechanisms—though we have no specific theoretic reason for predicting this. They may more readily identify a missing piece that looks different and connect the gears to make the machine whole again. The effect of troubleshooting and spinning on the memory task suggests that any impact these behaviors have on learning may not be specific to causal learning and may impact learning about gears more broadly.

Some aspects of parents' behavior in the exhibit predicted children's performance on the follow-up tasks. Parents' troubleshooting behavior in the exhibit interaction was negatively related to children's later time spent on the generalization task. This could be explained by children's existing understanding of gear mechanisms; children who already understood how gears connect might have required less troubleshooting on the part of the parent and might have been more likely to persist when given a chance to work on their own. In the explain condition, parents were asked to prompt children to explain how the gears work, and subsequently spent less time troubleshooting—perhaps because they wanted to take on a "teacher" role (see Bonawitz et al., 2011) or because children connected fewer gears in this condition. These results suggest that when less time is spent by parents fixing gears for their children, their children may be more likely to persist in solving problems when alone. Children learn more effectively from a combination of observation and self-generated action than from observation alone (e.g., Baldwin, Markman, & Melartin, 1993; Gerson & Woodward, 2013; Kushnir & Gopnik, 2005). Children's own troubleshooting allows them to see the consequences of their actions on the gear machines they are building in a way that observing others' actions may not.

Parents' explanatory questions were also related to longer time spent by children on the generalization task. Questions generated by parents (and the dialog that followed) may give children a more causally rich understanding of gears and thus encourage their persistence in a later solo task. Alvarez and Booth (2014, 2015), for example, have suggested that preschoolers engage more in a causally relevant task when given rich rather than weak explanations of causal mechanisms. Similarly, there are numerous benefits of children generating explanations on learning (e.g., Walker, Lombrozo, Williams, Rafferty, & Gopnik, 2017). Parents who simply solve the problems that arise for their children during the exhibit interaction instead of allowing children to solve those problems themselves may be limiting children's willingness or ability to explore problems when they arise. When parents solve problems for children during free play, children might not learn what to do when the gears do not turn or do not connect properly and as a result feel less inclined to persist and try new things when they encounter problems in solo play.

Children's explanations did not predict a better understanding of the gear mechanism on the follow-up tasks, in contrast to the results of previous research by Legare and Lombrozo (2014). There are several possible reasons for this. In this prior study, the manipulation was specific to the follow-up tasks (children were asked to explain the machine presented to them in this task). In this study, we used the amount children talked about gears during the museum interaction to predict scores on the outcome tasks. Furthermore, children engaged in relatively little explanatory talk in our more naturalistic setting. A general prompt to parents to encourage their children to explain during the course of parent–child interaction resulted in far less explanation from children than previous research in which children were asked to explain how a particular gear machine worked.

One limitation of this study is that because of the age of our participants (4- to 6-year-olds), we only examined limited kinds of causal knowledge about gears. For instance, explicit recognition that connected gears must spin in opposite directions and recognizing that the speed with which a gear spins is related to the size of the gear both develop between ages 7 and 11 (Dixon & Bangert, 2002; Lehrer & Schauble, 1998); here we include only younger children. Examining the extent to which interaction between parents and children at a museum promote discovery of these causal principles would be a compelling topic for future research. What we could examine were operationalizations of children's persistence and problem-solving behaviors, which were related to certain aspects of parent–child interaction. In addition, the younger age range we worked with here better reflects the ages at which children may begin to interact with these museum exhibits.

Our data have the potential to inform research on guided play. Adult involvement in children's exploration is most helpful when children are still in control and allowed to solve problems themselves (Weisberg, Hirsh-Pasek, Golinkoff, Kittredge, & Klahr, 2016; Weisberg et al., 2013; see also Mayer, 2004). Our task differs from previous research, however, in that the role of parents was to facilitate by asking questions, encouraging exploration, and prompting children to try to solve problems independently, rather than to use "teachable moments" in children's play as an opportunity to provide their own explanations to teach a new concept (Honomichl & Chen, 2012). The differences we observed in parent–child interactions as a result of the conversation card intervention may have a larger impact on learning outcomes after longer more sustained interactions with hands-on exhibits or repeated interactions over time. The divergent patterns of behavior that parents and children engaged in related to children's performance on the outcome measures in multiple ways, demonstrating that there are multiple ways that parents and educators may facilitate children's causal understanding.

In sum, these data demonstrate that asking parents to encourage their children to explain does change both parents' and children's behaviors and that asking parents to encourage their children to explore changes children's behaviors. Engaging in these behaviors, in turn, might impact how children come to understand causal mechanisms. These effects potentially speak to more general trends in how parents and children interact in learning environments. For example, parents who are more likely to ask questions of their children may be more likely to ask questions in our study, regardless of condition. Nonetheless, we found that cues to explaining motivated parents to engage in more behaviors that support learning (such as asking questions) and fewer behaviors that might hinder learning (such as fixing problems for children, instead of allowing independent troubleshooting) than when no cues were given. Cues to explore were equally as effective at encouraging parents to help their children engage more with the exhibit to build more complex machines, which should additionally aid in how children engage with and learn from the exhibit. This is particularly important to museums and other educational institutions, which aim to provide parents with suggestions about a variety of ways to engage children in playful and open-ended ways of learning.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Table S1. Predicting Children's Behavior From Parent Past Behavior (Previous 10 s) and Concurrent Behavior (Same 10-s)

Table S2. Probit Regression Analyses of Explanatory and Exploratory Behavior Predicting Correct Answers on the Memory and Mechanism Tasks—Full Table

Table S3. Regression Analyses of Explanatory and Exploratory Behavior Predicting Correct Answers on the Reconstruction and Generalization Tasks—Full Table