Parents' Causal Talk: Links to Children's Causal Stance and Emerging Scientific Literacy

Amy E. Booth

Margaret Shavlik

Vanderbilt University

Catherine A. Haden

Loyola University Chicago

Revision Date: June 5, 2020

Author Note

PLEASE NOTE: For the definitive final version of this manuscript, please see Developmental Psychology https://doi.org/10.1037/dev0001108

This work was graciously funded by the National Science Foundation (grant #1535102) awarded to Amy E. Booth and Catherine A. Haden. Special thanks to Brian French for his comments on a previous draft, and to Kimberly Brenneman, Maureen Callanan, Daryl Greenfield, Robin Gose, Cristine Legare and Ala Samarapungavan for their advisory role in this research. We are also grateful to the children and families who generously contributed their time to this project.

Abstract

In order to explore the potential contribution of parents' causal talk to preschooler's emerging scientific literacy and related interests, we observed 153 parent-child dyads playing together in a museum and in the lab. As in previous work, the frequency with which parents referenced causal information in their speech predicted the strength of their children's causal stance. In addition, the frequency with which parents invited their children to explain causal phenomena, but not the frequency with which they provided explanations to their children, was related to children's scientific literacy. These associations held even when controlling for children's parent-reported exposure to science in the home, as well as their general cognitive skills. Although causal conclusions are precluded by the correlational design, this research is consistent with the possibility that parents begin shaping their children's scientific engagement and literacy when they are as young as two years of age.

Keywords: parent input, scientific literacy, causal stance

Parents' Causal Talk: Links to Children's Causal Stance and Emerging Scientific Literacy

Research scientists and policy makers alike continue to highlight the importance of promoting education and engagement in science, technology, engineering and mathematics (STEM) in fortifying economic prosperity, physical health, and psychological well-being (Bybee, 2010; National Research Council, 2012). The push to promote STEM education has set in motion widespread reforms in the way that science is taught in schools (e.g., National Research Council, 2013). Substantial research effort has also been invested in characterizing the development of scientific literacy and interests throughout grade-school (Alexander, Johnson, & Kelley, 2012; Bathgate, Schunn, & Correnti, 2014), and identifying aspects of experience inside and outside the school that help shape that developmental course for individual children (e.g., Dunbar & Klahr, 1989; Erdosne Toth, Klahr, & Chen, 2000; Kuhn et al., 1988; Meyer, Wardrop, & Hastings, 1992; Zimmerman, 2000).

More recently, some have suggested that in order to fully understand the origins of children's scientific literacy and engagement, and ultimately optimize outcomes, we must focus our efforts earlier (see Brenneman, 2011). Although implementation has been slow, several promising kindergarten and preschool science curricula have been developed with this goal in mind (e.g., Gelman, Brenneman, Macdonald, & Roman, 2010; Gonzalez et al., 2010; Peterson & French, 2008). Data from newly developed tools for measuring early scientific literacy further reinforce the potential value of focusing more attention on preschool science. Specifically, the Lens on Science (Greenfield, 2015) reveals substantial knowledge, and variability, in this domain by 3 years of age. Young children's performance on this adaptive test reflects not just factual knowledge, but also familiarity with key cross-cutting concepts (e.g., patterns, cause and effect, systems models, structure and function), and processing skills (e.g., asking questions, analyzing and interpreting data) that are at the heart of scientific inquiry.

Evidence suggests that children's attitudes towards science are also taking shape quite early. For example, utilizing their Puppet Interview of Competence in and Enjoyment of Science (PICES), Patrick and colleagues (2008) found that although kindergarteners had an overall positive view of science, individually distinct profiles of reported liking of, competence with, and easy of learning science were also evident (also see Mantzicopoulos, Patrick, & Samarapungavan, 2008; Patrick, Mantzicopoulos, & Samarapungavan, 2009; Pell & Jarvis, 2001). Other work by Alvarez and Booth (2016) suggests that variability in children's degree of interest in the causal structures underlying scientific knowledge and inquiry potentially emerges even earlier. Specifically, this work revealed stability in children's causal stance across inquiry and preference-based tasks, as well as across a month-long time delay, by four years of age. Moreover, when even younger three-year-old children were evaluated on their preferences for causal vs. non-causal descriptions of novel artifacts and animals, Alvarez and Booth (2015) found that the scores of individual children varied substantially.

Importantly, experiences in the home may be critical to nurturing these roots of scientific literacy and interests as they begin to take hold. It is widely held that parents exert considerable influence in broadly shaping the attitudes, learning, and achievement of their young children (Bandura & Walters, 1963; Davis-Kean, 2005; Jacobs & Eccles, 2000; Rogoff et al., 1993). Several studies have more specifically described how parents support the scientific thinking of their preschool and school-age children (e.g., National Research Council, 2009; Callanan & Jipson, 2001; Crowley & Galco, 2001; Fender & Crowley, 2007; Haden et al., 2014). For example, children more effectively process elements of cause and effect in museum exhibits after exploring them with their parents, as opposed to with a peer, or on their own (Crowley et al., 2001). Moreover, Mantzicopoulos, Patrick and Samarapungavan (2013) report significant correlations between family support for science generally speaking, and measures of both kindergartener's scientific literacy and interests. Alvarez and Booth (2016) also report a moderate correlation between mothers' causal talk and the strength of their preschool children's causal stance, marking the earliest developmental window in which an association between parent input and children's science-related attitudes has thus far been observed.

Although this body of research provides a rich picture of the early emergence of scientific knowledge and interests, much remains to be learned about the role that parents might play in nurturing development in this domain. The goals of the current investigation were three-fold. First, we sought to replicate the findings of Alvarez and Booth (2016) linking parents' causal talk to children's causal stance, in a larger, more diverse, and younger sample. Given that reported relations between home science experiences and science literacy are stronger in earlier grades (Meyer et al., 1992), and in light of the outsized influence parents generally have on children's development before they enter school, we expected to observe comparable, if not stronger, correlations.

Second, we sought to expand the scope of potential child outcomes under consideration by evaluating whether parent causal talk also relates directly to children's early scientific literacy, as measured by the Lens on Science (Greenfield, 2015). In light of evidence indicating that parents' talk influences children's science-related exploration and learning in circumscribed contexts (Fender & Crowley, 2007; Marcus, Haden, & Uttal, 2018; Willard et al., 2019), we also expected an association to our broader assessment of scientific literacy. To the extent that early interests in science propel scientific literacy, an indirect effect of parent input through children's causal stance might also be evident.

Third, and subordinate to our second goal, we pursued a more fine-grained consideration of what aspects of parent input might be especially relevant to supporting children's early scientific knowledge. In particular, we differentiated causal talk that directly provides explanations for causal phenomenon from talk that invites the child to generate these explanations themselves. Substantial research has been devoted to documenting the frequency and quality of explanations offered by parents to their young children in a variety of settings (Callanan, Castaneda, Luce, & Martin, 2017; Callanan & Jipson, 2001; Callanan & Oakes, 1992; Haden, 2010; Tenenbaum & Callanan, 2008; Van Schijndel & Raijmakers, 2016), on the explicit or implicit premise that these are likely foundational to promoting scientific literacy. In addition, evidence and theory suggests that these explanations are salient to, and sought out by, young children (e.g., Chouinard, Harris, & Maratsos, 2007; Gopnik, 2000). Indeed, children as young as three years of age are sensitive to the quality of explanations provided by adults and are generally not content to drop a line of questioning if they do not feel that they have received an adequate response (Frazier, Gelman, & Wellman, 2009; Kurkul & Corriveau, 2018).

However, Bonawitz et al. (2011) note that pedagogical explanations might actually curtail learning under some circumstances by undermining children's own exploration and discovery process. In addition, a now substantial literature highlights the distinct potential of self-generated causal explanations to promote causal learning and hypothesis revision in young children (Legare & Lombrozo, 2014; Walker, Bonawitz, & Lombrozo, 2017; Walker, Lombrozo, Legare, & Gopnik, 2014; Walker, Lombrozo, Williams, Rafferty, & Gopnik, 2016; but see Marcis & Sobel, 2017; Willard et al., 2019). Thus, it is possible that the degree to which parents scaffold children's own generation of explanations might be more strongly related to early scientific literacy than the degree to which they offer fully articulated explanations themselves.

In order to address these questions, we observed a large and diverse sample of 3-year-olds engaged in scientific co-play with a parent at both a children's museum and in the laboratory. Parent causal talk across these contexts was evaluated in relation to a variety of child measures, including assessments of their causal stance, scientific literacy, and broader cognitive skills. Although this correlational approach will not support definitively causal conclusions, it represents a critical first step in determining whether parent talk is a viable foundation for the development of early scientific interests and literacy.

Method

Participants

Our sample included 153 children (71 male) from the Austin, Texas area. Participating children were three years old at the first session (M = 3.41, SD = 0.26, range = 3.01–3.92). Children were recruited through an existing database of families interested in participating in research, as well as in-person at the science museum where data collection took place. Children did not have any diagnosed developmental disorders or hearing impairments. An additional 8 children were excluded from analyses due to insufficient English proficiency (as indicated by parent rating of 1 or 2 on a 5-point scale; n = 3) or failure to cooperate with task instructions (n = 5). Additional missing data is described on a task by task basis in the results section.

Based on parent report, 13.1% of participating children were African American, 73.9% were White, 2.6% were Asian, and 10.5% identified as multiple races or "other." In addition, 30.1% of these children were also identified by their parents as being Hispanic or Latino. With respect to maternal education 27.5% held no more than a high school degree, 6.5% held an

Associates or Technical degree, 38.6% had a four-year bachelor's degree, and 8.5% held an advanced degree.

Design and General Procedures

The data for the current investigation was collected as part of a larger study that included measures of causal reasoning and executive function (The University of Texas at Austin, IRB protocol 2015-05-0054: "Exploring Individual Differences in Preschoolers' Causal Stance"). Tasks were run over five sessions, spread across an average of approximately 5 months. The first session took place at the Thinkery, a children's science museum, and all subsequent sessions took place at our research lab at the University of Texas. Measures collected at each session (along with their analytic role) are outlined in Table 1. Parents consented for both themselves and their child by signing a single consent form in person. All sessions were video recorded for offline coding. Upon completion of each visit, the family was compensated, and each child was given a book to take home.

Measures and Stimuli

NIH Toolbox Early Cognition Battery (NIH-ECB). In order to control for general cognitive skills that might impact performance on our measure of scientific literacy (Bauer & Booth, 2019; Tolmie, Ghazali, & Morris, 2016), we tested all children on the NIH-ECB, which consists of the Picture Vocabulary (*language, Session 1*), Flanker (*attention and executive function, Session 3*), Dimensional Change Card Sort (*executive function and attention, Session 4*), and Picture Sequence Memory (*episodic memory, Session 5*) sub-tests. The NIH-ECB is designed for children three to six years old, and, on average, each sub-test takes between five and ten minutes to administer. See Zalazo and Bauer (2013) for more details.

Home science exposure. In order to address the possibility that exposure to science-related materials and activities at home is related to children's early scientific literacy and interests, we asked parents during Session 1 to report on 1) the number of science books, toys, and apps and/or computer games that their child has access to in the home (coded into 1-5, 6-20, 21-50 and over 50 bins and then summed across type) 2) the frequency (on a seven-point scale) with which they participate in science activities like reading science books and conducting experiments with their child (1 = never to 7 = almost every day) and 3) how often (on a seven-point rating scale) they visit science fairs or museums with their children (1 = never to 7 = every week or two). See Jacobs and Bleeker (2004) and Meyer (1990) for similar assessments.

Causal stance. The strength of children's causal stance (i.e., their interest in causal information) was measured as the average performance across three tasks. All causal stance tasks were video-recorded to facilitate coding. The stimuli are provided as Supplemental Materials.

Causal preference. This task, administered during Session 1, consisted of 10 trials, on each of which the child viewed a novel animal or artifact (created with Spore® software) on a computer screen (see Alvarez & Booth, 2016). An interesting physical feature (other than the face) of each item was obscured by a red rectangular button. Participants could choose to press either the rectangular button to see the hidden part or to press a round button at the bottom of the screen to hear a pre-recorded causally relevant description of the item (e.g., This one rattles its tail to scare other animals away). Prior to testing, the experimenter illustrated how the procedure worked with two familiar items (a cat and a car). For these items, the experimenter both revealed the hidden part and played the causal description. The experimenter then forwarded to a screen picturing a spaceship blast-off and explained to the child that they were pretending to travel to planet Zenon, where they would get to see lots of things they have never seen before. The experimenter then explained that they would only be able to choose to either see the hidden part or hear the description of each one. Participants indicated their choice on each trial verbally and/or by touching one of the buttons. The proportion of trials of which children chose to hear the causal descriptions served as the dependent variable. All scores were coded from video, with 20% double-coded by a second independent researcher. Because child responses were so easily distinguishable, coders were in 100% agreement.

Novel picture inquiry. This task, administered during Session 2, began with the experimenter placing 10 cards, each picturing an unfamiliar artifact (e.g., a motorcycle shock mount), on the table facing the child (see Supplemental Materials). The experimenter then asked "Which of these do you want to learn about?" Once the child chose a picture, the experimenter moved the other cards to the side and prompted the child to ask questions about the selected item (*e.g.,* "What do you want to know about this one?"). The experimenter answered questions produced by the child in an informative, but brief and circumscribed way, according to a prespecified list of responses. For example, if a child asked, 'What does it do?' when looking at an orange juicer, the experimenter responded 'You use it to squeeze the juice out of fruit!" Following Kemler Nelson et al. (2004), the experimenter initially responded to the ambiguous question 'What is it?' by providing a novel label (e.g., 'It's a dax!'), but provided information about the object's function if the child persisted in asking this question again about the same item. When a participant stopped asking questions about the chosen card, the experimenter put the remaining cards back in front of the child, saying "Which do you want to learn about next?" The experimenter repeated this procedure until all 10 cards were chosen. To maximize accuracy, two coders independently coded all transcripts for instances of causal and non-causal questions (see Alvarez & Booth, 2016 for coding details). Although the initial interclass correlation based on the proportion of questions that elicited causal information was high (.92), discrepancies of greater than 20% for any individual subject were further resolved by discussion.

Novel object inquiry. This task, administered during Session 5, was included as a supplement to the novel picture inquiry task (used in previous work) with the thought that more naturalistic play with real objects might elicit more question asking from such young participants. The experimenter began by presenting the child with six unusual objects (see Supplemental Materials) and instructing them to play with the objects however they wanted, and to ask the experimenter anything they wanted to know about them at any time. Objects were put away if the child said that they were all done, or 10 minutes had passed. Until that time, the experimenter silently inspected the objects and responded to questions in the same manner as in the novel picture inquiry task. Coding proceeded in the same manner as described for the novel picture inquiry task. Interclass correlation was .96, with discrepancies again further resolved through discussion.

Lens on Science. This measure, administered during Session 1, assesses preschoolers' knowledge in the domains of life, earth/space and physical/energy science, as well as understanding of eight scientific 'process skills' (e.g., observing, questioning, experimenting). The test is administered individually via touchscreen tablet. Children are adaptively presented with 35-40 questions (from a bank of 389 possibilities) over the course of approximately 15 minutes. Children select their answers by touching one of three pictured alternatives. See Greenfield (2015) for more details.

Parent causal talk. Parent causal talk was observed in both a children's museum (Session 1) and the lab (Session 2). In both settings, parent-child dyads were given no specific instructions as to how to interact, and were given 10 minutes to play freely. In the museum, participants explored a launcher exhibit where they could build airplanes out of a variety of foam parts and test their flight properties using an air cannon. In the lab, participants were presented with a tub of water and nine transparent container-blocks varying in shape (e.g., cylinder, cube), as well as type and quantity of contents (e.g., pennies, pom-poms). A photo of these materials can be seen in Supplemental Materials.

Although our approach to coding parents' talk was heavily informed by the work of Callanan and colleagues on explanatory talk (e.g., Beals, 1993; Callanan & Jipson, 2001; Callanan & Oakes, 1992; Crowley & Galco, 2001; Tenenbaum & Callanan, 2008), we focused more narrowly on causally oriented talk (see Alvarez & Booth, 2016). We further differentiated between types of causally oriented talk, with a particular focus on causal explanations and invitations to explain. To optimize efficiency and reliability of coding, we opted to divide the 10-minute activity into 60s blocks. For each block, coders recorded whether the parent produced 1) a causal explanation (e.g., "that block sinks because it has more pennies in it than the floating block"), 2) an invitation for the child to explain a causal phenomenon (e.g., "Why did this block sink and that one float even though they have the same thing inside?"), and 3) any other causally relevant utterance (e.g., a prediction or direction like "Feel how heavy this one is" or "What do you think will happen if we drop them both in the water?"). See Table 2 for additional examples. Utterances were coded as causally oriented even if the information provided in that utterance was not technically correct (e.g., referencing size instead of density/weight). The proportion of windows (out of a maximum of 10), in which parents produced any causal utterance, as well as the proportion of windows in which they specifically produced an explanation or an invitation, served as the key dependent variables. A second researcher independently coded 20% of the transcripts. Interclass correlation was .81 for causal talk overall, and .88 and .99 for causal explanations and invitations to explain, respectively.

Results

Missingness was high for all three measures of causal stance due to procedural drift (preference task), children's failure to produce any questions (both inquiry tasks), as well as an unfortunate technical recording error (object inquiry task). There was also elevated attrition in the last session that further impacted missingness in the object inquiry and NIH picture sequence tasks. Rates of missingness on key variables, and explanations thereof, are provided in Table 3. In order to address missing data in a maximally unbiased manner, we conducted 100 iterations of multiple imputation, including all variables relevant to our analyses, as well as a variety of demographic measures (age, ethnicity, race, gender, maternal education). Although the data were not Missing Completely at Random (MCAR) according to Little's test (Little, 1988), the pattern of results reported below mirrored that observed in the non-imputed data, suggesting that the data were likely Missing at Random (MAR). Therefore, the resulting pooled dataset (with the full sample size of 153) was used for all subsequent analyses.

Composite scores for total parent causal talk, explanations, and invitations to explain (averaged across the museum and lab setting), children's causal stance (averaged across the preference and inquiry tasks), and the NIH-ECB (using the Age-Corrected Standard Scores; see NIH Toolbox Administrator's Manual and Casaletto et al., 2015) were calculated after imputation of values for the component measures (see Table 4 for means and standard deviations). Although causal talk was common, occurring in over 70% of coded windows, the frequency of causal explanations and invitations to explain was much lower (hovering around

10%), likely commensurate with parent expectations regarding the linguistic and conceptual capabilities of their children (see Palmquist & Crowley, 2007 and Marcus, Haden & Uttal, 2018).

In order to evaluate our first research question regarding linkages between parents' causal talk and children's causal stance, we first examined bivariate correlations between key variables. The strength of children's causal stance did indeed correlate with parents' causal talk ($r = .30$, $p = .004$), thereby replicating Alvarez and Booth (2016). Causal stance also correlated significantly with overall cognitive capabilities as measured by the NIH-ECB ($r = .35$, $p = .005$). In order to examine the effect of parents' causal talk on children's causal stance over and above these child cognitive factors, as well as broader experiential factors, we conducted a multiple regression predicting children's causal stance from parent causal talk, children's scores on the NIH-ECB, and parent reported home science exposure. The resulting regression equation was significant, $F(3,152) = 13.32$, $p < .001$. Parent causal talk was a significant predictor of children's scientific literacy ($p = .008$), reflecting a moderate effect size ($sr_1 = .26$). With respect to our control variables, children's cognitive skill was also significant with a moderate effect size ($p <.001$, $sr_2 = .30$), but home science exposure was not ($p = .900$). See Table 5.

In order to address our second and third research questions regarding relationships between parents' causal talk and early scientific literacy, we again first considered the relevant bivariate correlations. Although neither parents' overall causal talk, nor their causal explanations, correlated with children's scientific literacy ($rs = .11$ and $.04$, respectively, $ps > .21$), there was a significant positive association between parents' invitations for children to explain and children's scientific literacy ($r = .23$, $p = .007$). Scientific literacy scores also correlated with home science exposure ($r = .17$, $p = .041$) and overall cognitive functioning ($r = .52$, p < .001; also see Bauer & Booth, 2019; Greenfield, 2015; Tolmie et al., 2016). We therefore conducted a multiple regression predicting performance on the Lens on Science from parent causal invitations, again including children's NIH-ECB scores and parent reported home science exposure as control variables. The resulting regression equation was significant, F (3, 152) = 21.77, $p < .001$. Parent causal invitations were a significant predictor of children's scientific literacy ($p = .025$), reflecting a moderate effect size ($sr_1 = .18$). With respect to our control variables, children's cognitive skill was significant with a large effect size ($p < .001$, $sr_2 = .48$), but home science exposure was not ($p = .743$). See Table 6.

Although children's causal stance did correlate with their scientific literacy ($r = .43$, $p < .001$), it did not correlate with parents' invitations to explain ($r = .10$, $p = .360$). This, in combination with the fact that scientific literacy failed to correlate with parents' overall causal talk ($r = .11$, $p = .206$), precludes the possibility that causal stance partially mediates the association between parent input and scientific literacy observed here. We therefore did not further pursue an indirect effects analysis as initially planned.

Discussion

In this study, we sought to broaden our understanding of relationships between parent input and children's early scientific literacy and related causal interests. The investigation yielded two key observations. First, the degree to which parents generally talk about causally relevant information, the stronger their child's causal stance is likely to be. Second, the degree to which parents specifically invite their children to generate their own explanations for causal phenomenon, the more advanced their scientific literacy is likely to be. Although ambiguous regarding underlying causal mechanisms, these findings highlight the potential importance of parents in shaping children's early engagement and success in science.

The observed relationship between parent's causal talk and children' causal stance replicates Alvarez and Booth (2016) with a much larger sample, thereby lending support to the veracity of this finding. By including more diverse and younger children, the current study also enhances its generalizability. Together, this work highlights the possibility that parents play a foundational role in shaping children's early attunement to, and interest in, the causal structure of the world around them.

The observed association between parent input and scientific literacy was somewhat more nuanced. Specifically, while parent's overall emphasis on causal information did not predict children's performance on the Lens on Science measure, the degree to which parents invited their children to produce their own causal explanations did. This association stands in further contrast to the observed failure of parent's own causal explanations to predict children's scientific literacy. On its surface, this last result might seem surprising. Indeed, it seems entirely reasonable to expect that explaining causal phenomena to a child should help build their knowledge of science. Yet ours is not the first study to find no relationship between parent's explanations and children's learning (Van Schijndel et al, 2016).

To understand this result, it is useful to note that parents' explanations are not always fully formed or accurate (Crowley et al., 2001; Snow & Kurland, 1996). Indeed, although we did not formally code parent input for accuracy in the current work, the explanations offered were entirely consistent with this characterization, often providing incomplete or underspecified information. To the extent that these 'explanatoids' promote scientific literacy, they are thought to do so by encouraging children to notice key aspects of causal phenomenon and by providing a framework for developing inquiry skills (Fender & Crowley, 2007). It might be that these broader influences need more time to be reflected in developmental outcomes. It is also important to keep in mind that even well-articulated explanations offered by parents might miss their mark if they are incommensurate with a child's current state of knowledge or reasoning skills. Therefore, as we assess predictive relations between parent input and longer-term outcomes in our ongoing work, it will be important to consider both the quality of parent explanations, as well as the degree to which they are responsive to the interests, knowledge and skills of individual children (Chouinard et al, 2007). It will also be important to assess whether older children, with stronger language and cognitive abilities, are generally better able to capitalize on explanations provided by others to directly build their conceptual knowledge (Crowley et al, 2001; Horne, Muradoglu, & Cimpian, 2019).

Note that inviting children to explain causal phenomenon for themselves might help bypass these potential impediments to learning by encouraging children to engage the available information at whatever level makes sense to them, and to focus on what they personally find to be most relevant to their ongoing thought processes. Indeed, the fact that parent invitations to their children to explain uniquely predicted scientific literacy in the current investigation is consistent with mounting evidence regarding the power of self-generated explanation to propel learning, particularly in the context of causal phenomenon (Bonawitz et al., 2009; Bonawitz et al., 2011; Legare, Schult, Impola, & Souza, 2016). In their recent review of this literature, Busch, Willard and Legare (2018) explain how generating explanations helps children connect their current understanding of how the world works with the evidence at hand, highlighting inconsistencies and motivating further exploration. This in turn supports children's optimal elaboration, or revision of, causal beliefs that are foundational to scientific knowledge (Walker, Bonawitz, & Lombrozo, 2017; Walker et al., 2014; Willard et al., 2019).

Importantly, both of the key findings from this study maintained even after controlling for the general cognitive capabilities of children (including both their vocabulary and executive functioning), as well as other aspects of the home environment that might support children's emerging scientific knowledge and interests (e.g., number of science-themed books and toys, frequency of science-related activities and excursions). Although these cognitive and environmental factors correlated significantly with scientific literacy, and to a lesser extent with children's causal stance, parent input also uniquely contributed to explaining individual variability in both cases. This is consistent with the idea that parent-child interactions offer a particularly potent context for intergenerational transmission of attitudes, beliefs, and knowledge (e.g., Bandura & Walters, 1963; Fivush, 1994; Thompson, 2006).

Although controlling for potential third variables strengthens the conclusions that can be drawn from this study, the correlational design remains limiting. In particular, the directionality of effects cannot be clearly specified based on the available data. It remains entirely possible that children's pre-existing interests in causal information and/or their scientific knowledge elicit different kinds of talk from their parents. If parents know children are interested in understanding how things work, and have sufficient knowledge to understand causal mechanisms, then they might well be more likely to offer up this type of information, or to encourage their children to try to figure out how things work through independent exploration and explanation. This idea of reciprocal influences is central to theories of socialization (e.g., Holden, 2010; Kuczynski & Mol, 2015; Maccoby, 2007), and has been discussed explicitly in the context of scientific literacy by Callanan and Jipson (2001). In order to help clarify the causal directionality of the effects reported here, we are currently collecting longitudinal data from a subset of participants. In these and broader efforts, it will also be important to consider children's contributions to conversations with their parents around scientific phenomena in a variety of contexts. For example, coding children's questions and the responses offered by parents might be revealing about the degree to which children or their parents are driving these conversations.

To the extent that ongoing investigations confirm that parent input predicts children's *subsequent* interests and knowledge in the domain of science, it will highlight the potential value of parent-focused interventions for promoting children's engagement and success in STEM. In particular, the work thus far suggests that encouraging parents to prompt their children's self-generated explanations of causal phenomenon might be a particularly powerful approach. Insights like these are important because too many of our children, particularly those from socioeconomically disadvantaged families, are entering school inadequately prepared to learn science (e.g., Bustamante, White, & Greenfield, 2018; Curran & Kellogg, 2016; Greenfield et al., 2009; Janus & Duku, 2007). And, unfortunately, early scientific knowledge is predictive of longer-term success in this domain as children progress through elementary and middle school (Morgan, Farkas, Hillemeier, & Maczuga, 2016; also see Byrnes, Miller-Cotto, & Wang, 2018 for related discussion). New approaches to strengthening the foundations of children's causal stance and scientific knowledge may be instrumental in optimizing the achievement of all children.

References

Alexander, J. M., Johnson, K. E., & Kelley, K. (2012). Longitudinal analysis of the relations between opportunities to learn about science and the development of interests related to science. *Science Education, 96*(5), 763-786. doi:10.1002/sce.21018

Alvarez, A., & Booth, A. E. (2015). Preschoolers prefer to learn causal information. *Frontiers in Psychology, 6*(60). doi:10.3389/fpsygg.2015.00060

Alvarez, A., & Booth, A. E. (2016). Exploring individual differences in preschoolers' causal stance. *Developmental Psychology, 52*(3), 411-422. doi:10.1037/dev0000085

Bandura, A., & Walters, R. (1963). *Social Learning and Personality Development*. New York: Hold Rinehart and Wilson.

Bathgate, M. E., Schunn, C. D., & Correnti, R. (2014). Children's motivation toward science across contexts, manner of interaction, and topic. *Science Education, 98*(2), 189-215. doi:10.1002/sce.21095

Bauer, J.-R., & Booth, A. E. (2019). Exploring potential cognitive foundations of scientific literacy in preschoolers: Causal reasoning and executive function. *Early Childhood Research Quarterly, 46*, 275-284. doi:10.1016/j.ecresq.2018.09.007

Beals, D. (1993). Explanatory talk in low-income families' mealtime conversations. *Applied Psycholinguistics, 14*(4), 489-513. doi:10.1017/S0142716400010717

Bonawitz, E., Shafto, P., Gweon, H., Chang, I., Katz, S., & Schulz, L. (2009, July). The double-edged sword of pedagogy: Modeling the effect of pedagogical contexts on preschoolers' exploratory play. *Proceedings of the Cognitive Science Society, Amsterdam, Netherlands.* Retrieved from http://csjarchive.cogsci.rpi.edu/Proceedings/

Bonawitz, E., Shafto, P., Gweon, H., Goodman, N. D., Spelke, E., & Schulz, L. E. (2011). The double-edged sword of pedagogy: Instruction limits spontaneous exploration and discovery. *Cognition, 120*(3), 322-330. doi:10.1016/j.cognition.2010.10.001

Brenneman, K. (2011). Assessment for preschool science learning and learning environments. *Early Childhood Research and Practice, 13*(1), 150-158. Retrieved from http://eric.ed.gov/

Busch, J. T., Willard, A. K., & Legare, C. H. (2018). Explanation scaffolds causal learning and problem solving in childhood. In M. M. Saylor & P. A. Ganea (Eds.), *Active learning from infancy to childhood* (pp. 113-127). Champaign: Springer. doi:10.1007/978-3-319-77182-3_7 .

Bustamante, A. S., White, L. J., & Greenfield, D.B. (2018). Approaches to learning and science education in Head Start: Examining bidirectionality. *Early Childhood Research Quarterly, 44*, 34-42. doi:10.1016/j.ecresq.2018.02.013

Bybee, R. (2010). What is STEM education? *Science, 329*(5995), 996. doi:10.1126/science.1194998

Byrnes, J. P., Miller-Cotto, D., & Wang, A. H. (2018). Children as mediators of their own cognitive development: The case of learning science in kindergarten and first grade. *Journal of Cognition and Development, 19*(3), 248-277. doi:10.1080/15248372.2018.1470975

Callanan, M. A., Castaneda, C. L., Luce, M. R., & Martin, J. L. (2017). Family science talk in museums: Predicting children's engagement from variations in talk and activity. *Child Development, 88*(5), 1492-1504. doi:10.1111/cdev.12886

Callanan, M. A., & Jipson, J. L. (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 settings* (pp. 21-49). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers. doi:10.4324/9781410600318

Callanan, M. A., & Oakes, L. M. (1992). Preschoolers' questions and parents' explanations: Causal thinking in everyday activity. *Cognitive Development, 7*(2), 213-233. doi:10.1016/0885-2014(92)90012-G

Casaletto, K. B., Umlauf, A., Beaumont, J., Gershon, R., Slotkin, J., Akshoomoff, N., & Heaton, R. K. (2015). Demographically corrected normative standards for the English version of the NIH Toolbox Cognition Battery. *Journal of the International Neuropsychological Society*, *21*(5), 378-391. doi: 10.1017/s1355617715000351

Chouinard, M. M., Harris, P. L., & Maratsos, M. P. (2007). Children's questions: A mechanism for cognitive development. *Monographs of the Society for Research in Child Development*, *72*(1), i-129. doi:10.1146/annurev.psych.59.103006.093659

Crowley, K., Callanan, M. A., Jipson, J. L., Galco, J., Topping, K., & Shrager, J. (2001). Shared scientific thinking in everyday parent-child activity. *Science Education, 85*(6), 712-732. doi:10.1002/sce.1035

Crowley, K., & Galco, J. (2001). Family conversations and the emergence of scientific literacy. In K. Crowley, C. D. Schunn, & T. Okada (Eds.), *Designing for science: Implications from everyday, classroom, and professional settings* (pp. 393-413). Mahwah, NJ: Lawrence Erlbaum Associates Publishers. doi:10.4324/9781410600318

Curran, F. C., & Kellogg, A. T. (2016). Understanding science achievement gaps by race/ethnicity and gender in kindergarten and first grade. *Educational Researcher, 45*(5), 273-282. doi:10.3102/0013189X16656611

Davis-Kean, P. E. (2005). The influence of parent education and family income on child achievement: The indirect role of parental expectations and the home environment. *Journal of Family Psychology, 19*(2), 294-304. doi:10.1037/0893-3200.19.2.294

Dunbar, K., & Klahr, D. (1989). Developmental differences in scientific discovery processes. In D. Klahr & K. Kotovsky (Eds.), *Complex information processing: The impact of Herbert A. Simon* (pp. 109-143). New York, NY: Psychology Press. doi:10.4324/9780203761618

Erdosne Toth, E., Klahr, D., & Chen, Z. (2000). Bridging research and practive: A cognitively based classroom intervention for teaching experimentation skills to elementary school children. *Cognition and Instruction, 18*(4), 423-459. doi:10.1207/S1532690XCI1804_1

Fender, J., & Crowley, K. (2007). How parent explanation changes what children learn from everyday scientific thinking. *Developmental Psychology, 28*(3), 189-210. doi:10.1016/j.appdev.2007.02.007

Fivush, R. (1994). Constructing narrative, emotion, and self in parent–child conversations about the past. In U. Neisser & R. Fivush (Eds.), *The remembering self: Construction and accuracy in the self-narrative* (Emory Symposia in Cognition, pp. 136-157). Cambridge: Cambridge University Press. doi:10.1017/CBO9780511752858.009

Frazier, B. N., Gelman, S. A., & Wellman, H. M. (2009). Preschoolers' search for explanatory information within adult–child conversation. *Child Development, 80*(6), 1592-1611. doi:10.1111/j.1467-8624.2009.01356.x

Gelman, R., Brenneman, K., Macdonald, G., & Roman, M. (2010). *Preschool pathways to science: Faciltating scientific ways of thinking, talking, doing, and understanding*. Baltimore: Paul H. Brookes Publishing Company.

Gonzalez, J. E., Pollard-Durodola, S., Simmons, D. C., Taylor, A. B., Davis, M. J., Kim, M., & Simmons, L. (2010). Developing low-income preschoolers' social studies and science vocabulary knowledge through content-focused shared book reading. *Journal of Research on Educational Effectiveness, 4*(1), 25-52. doi:10.1080/19345747.2010.487927

Gopnik, A. (2000). Explanation as orgasm and the drive for causal knowledge: The function, evolution, and phenomenology of the theory formation system. In F. C. Keil & R. A. Wilson (Eds.), *Explanation and Cognition* (pp. 299-323). Cambridge, MA: The MIT Press.

Greenfield, D. B. (2015). Assessment in early childhood science education. In K. Trundle, & M. Saçkes (Eds.), *Research in early childhood science education* (pp. 353–380). New York, NY: Springer Publishing. doi:10.1007/978-94-017-9505-0_16

Greenfield, D. B., Jirout, J., Dominguez, X., Greenberg, A., Maier, M., & Funccillo, J. (2009). Science in the preschool classroom: A programmatic research agenda to improve science readiness. *Early Education & Development, 20*(2), 238-264. doi:10.1080/10409280802595441

Haden, C. A. (2010). Talking about science in museums. *Child Development Perspectives, 4*(1), 62-67. doi:10.1111/j.1750-8606.2009.00119.x

Haden, C. A., Jant, E. A., Hoffman, P. C., Marcus, M., Geddes, J. R., & Gaskins, S. (2014). Supporting family conversations and children's STEM learning in a children's museum. *Early Childhood Research Quarterly, 29*(3), 333-344. doi:10.1016/j.ecresq.2014.04.004

Holden, G. W. (2010). Childrearing and developmental trajectories: Positive pathways, off-ramps, and dynamic processes. *Child Development Perspectives, 4*(3), 197-204. doi:10.1111/j.1750-8606.2010.00148.x

Horne, Z., Muradoglu, M., & Cimpian, A. (2019). Explanation as a cognitive process. *Trends in Cognitive Sciences, 23*(3), 187-199. doi:10.1016/j.tics.2018.12.004

Jacobs, J., & Bleeker, M. (2004). Girls' and boys' developing interests in math and science: Do parents matter? *New Directions for Child and Adolescent Development, 2004*(106), 5-21. doi:10.1002/cd.113

Jacobs, J., & Eccles, J. (2000). Parents, task values, and real-life achievement-related choices. In C. Sansone & J. Harackiewicz (Eds.), *Intrinsic and extrinsic motivation: The search for optimal motivation and performance* (pp. 405-439). San Diego: Academic Press. doi:10.1016/B978-012619070-0/50036-2

Janus, M., & Duku, E. (2007). The school entry gap: socioeconomic, family and health factors associated with children's school readiness to learn. *Early Education & Development, 18*(3), 375-403. doi:10.1080/10409280701610796a

Kemler Nelson, D. G., Chan Egan, L., & Holt, M. B. (2004). When children ask "What is it?" what do they want to know about artifacts? *Psychological Science, 15*(6), 384-389. doi:10.1111/j.0956-7976.2004.00689.x

Kuczynski, L., & Mol, J. D. (2015). Dialectical models of socialization. In W. F. Overton & P. C. M. Molenaar (Eds.), *Handbook of Child Psychology and Developmental Science* (7th ed., Vol. 1, pp. 1-46). Hoboken, NJ: Wiley. doi:10.1002/9781118963418.childpsy109

Kuhn, D., Amsel, E., O'Laughlin, E., Schauble, M., Leadbeater, B. J., & Yotive, W. (1988). *The development of scientific thinking skills.* San Diego: Academic Press. doi:10.5772/53885

Kurkul, K. E., & Corriveau, K. H. (2018). Question, explanation, follow-up: A mechanism for learning from others? *Child Development, 89*(1), 280-294. doi:10.1111/cdev.12726

Legare, C. H., & Lombrozo, T. (2014). Selective effects of explanation on learning during early childhood. *Journal of Experimental Child Psychology, 126*, 198-212. doi:10.1016/j.jecp.2014.03.001

Legare, C. H., Schult, C. A., Impola, M., & Souza, A. L. (2016). Young children revise explanations in response to new evidence. *Cognitive Development, 39*, 45-56. doi:10.1016/j.cogdev.2016.03.003

Little, R. J. (1988). A test of missing completely at random for multivariate data with missing values. *Journal of the American statistical Association*, *83*(404), 1198-1202. doi:10.1080/01621459.1988.10478722

Maccoby, E. E. (2007). Historical overview of socialization research and theory. In J. E. Grusec & P. D. Hastings (Eds.), *Handbook of socialization: Theory and research* (Vol. 45, pp. 3-41). New York: Guilford Press.

Mantzicopoulos, P., Patrick, H., & Samarapungavan, A. (2008). Young children's motivational beliefs about learning science. *Early Childhood Research Quarterly, 23*(3), 378-394. doi:10.1016/j.ecresq.2008.04.001

Mantzicopoulos, P., Patrick, H., & Samarapungavan, A. (2013). Science literacy in school and home contexts: Kindergarteners' science achievement and motivation. *Cognition and Instruction, 31*(1), 62-119. doi:10.1080/07370008.2012.742087

Marcis, D. M., & Sobel, D. M. (2017). The role of evidence diversity and explanation in 4- and 5-year-olds' resolution of counterevidence. *Journal of Cognition and Development, 18*(6), 358-374. doi:10.1080/15248372.2017.1323755

Marcus, M., Haden, C. A., & Uttal, D. H. (2018). Promoting children's learning and transfer across informal science, technology, engineering, and mathematics learning experiences. *Journal of Experimental Child Psychology, 175*, 80-95. doi:10.1016/j.jecp.2018.06.003

Meyer, L. (1990). *Parents' reports of kindgergarten, first- and second-grade children's out-of-school activities and their relationship to science ability* (Report No. 495). Champaigne, IL: University of Illinois at Urbana-Champaign. Retrieved from http://eric.edu.gov/

Meyer, L., Wardrop, J., & Hastings, N. (1992). *The development of science knowledge in kindergarten through second grade* (Report No. 549). Champaigne, IL: University of Illinois at Urbana-Champaign. Retrieved from http://eric.edu.gov/

Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher, 45*(1), 18-35. doi:10.3102/0013189X16633182

National Research Council. (2009). *Learning science in informal environments: People, places, and pursuits*. Washington, DC: The National Academies Press. doi:10.17226/12190

National Research Council. (2013). *Monitoring progress toward successful K-12 STEM education: A nation advancing?* Washington, DC: The National Academies Press. doi:10.17226/13509

National Research Council. (2012). *Rising to the challenge: US innovation policy for the global economy*. Washington, DC: The National Academies Press. doi:10.17226/13386

NIH Toolbox for Assessment of Neurological and Behavioral Function [Administrator's Manual]. Retrieved from https://nihtoolbox.force.com/

Palmquist, S., & Crowley, K. (2007). From teachers to testers: How parents talk to novice and expert children in a natural history museum. *Science Education, 91*(5), 783-804. doi:10.1002/sce.20215

Patrick, H., Mantzicopoulos, P., & Samarapungavan, A. (2009). Reading, writing, and conducting inquiry about science in kindergarten. *Young Children, 64*(6), 32-38. Retrieved from http://researchgate.net/

Pell, T., & Jarvis, T. (2001). Developing attitude to science scales for use with children of ages from five to eleven years. *International Journal of Science Education, 23*(8), 847-862. doi:10.1080/09500690010016111

Peterson, S. M., & French, L. (2008). Supporting young children's explanations though inquiry science in preshools. *Early Childhood Research Quarterly, 23*(3), 395-408. doi:10.1016/j.ecresq.2008.01.003

Rogoff, B., Mistry, J., Goncu, A., Mosier, C., Chavajay, P., & Brice Heath, S. (1993). Guided participation in cultural activity by toddlers and caregivers. *Monographs of the Society for Research in Child Development*, *58*(8), i-179. doi:10.2307/1166109

Snow, C. E., & Kurland, B. (1996). Sticking to the point: Talk about magnets as a context for engaging in scientific discourse. *Discourse, Learning, and Schooling*, 189-220. doi:cbo9780511720390.007

Tenenbaum, H. R., & Callanan, M. A. (2008). Parents' science talk to their children in Mexican-descent families residing in the USA. *International Journal of Behavioral Development, 32*(1), 1-12. doi:10.1177/0165025407084046

Thompson, R. A. (2006). Conversation and developing understanding: Introduction to the special issue. *Merrill-Palmer Quarterly, 52*(1), 1-16. doi:10.1353/mpq.2006.0008

Tolmie, A. K., Ghazali, Z., & Morris, S. (2016). Children's science learning: A core skills approach. *British Journal of Educational Psychology, 86*(3), 481-497. doi:10.1111/bjep.12119

Van Schijndel, T. J. P., & Raijmakers, M. E. J. (2016). Parent explanation and preschoolers' exploratory behavior and learning in a shadow exhibition. *Science Education, 100*(1), 153-178. doi:10.1002/sce.21193

Walker, C. M., Bonawitz, E., & Lombrozo, T. (2017). Effects of explaining on children's preference for simpler hypotheses. *Psychonomic Bulletin & Review, 24,* 1538-1547. doi:10.3758/s13423-016-1144-0

Walker, C. M., Lombrozo, T., Legare, C. H., & Gopnik, A. (2014). Explaining prompts children to privilege inductively rich properties. *Cognition, 133*(2), 343-357. doi:10.1016/j.cognition.2014.07.008

Walker, C. M., Lombrozo, T., Williams, J. J., Rafferty, A. N., & Gopnik, A. (2017). Explaining constrains causal learning in childhood. *Child Development, 88*(1), 229-246. doi:10.1111/cdev.12590

Willard, A. K., Busch, J. T., Cullum, K. A., Letourneau, S. M., Sobel, D. M., Callanan, M. A., & Legare, C. H. (2019). Explain this, explore that: A study of parent–child interaction in a children's museum. *Child Development, 90*(5), e598-e617. doi:10.1111/cdev.13232

Zelazo, P. D. & Bauer, P. J. (Eds.). (2013). National Institutes of Health Toolbox Cognition Battery (NIH Toolbox CB): Validation for children between 3 and 15 years. *Monographs of the Society for Research in Child Development, 78*(4).

Zimmerman, C. (2000). The development of scientific reasoning skills. *Developmental Review, 20*(1), 99-149. doi:10.1006/drev.1999.0497

Table 1

Study Measures and their Analytic Roles

Construct of Interest	**Analytic Role**	**Measurement**	**Session**
Causal talk (parent)	Predictor	Museum observation	1
		Laboratory observation	2
Causal stance (child)	Outcome	Causal Preference	1
		Novel Picture Inquiry	2
		Novel Object Inquiry	5
Scientific literacy (child)	Outcome	Lens on Science	1
General cognitive ability (child)	Control	NIH Toolbox Early Cognition Battery:	
		● Picture Vocabulary Test	1
		● Flanker Inhibitory Control & Attention	3
		● Dimensional Change Card Sort	4
		● Picture Sequence Memory	5
Home science exposure (parent)	Control	Parent survey	1

Table 2

Parent Causal Talk: Example Utterances for Code Types

Code Type	**Example Utterances**
Causal Explanation	This one is heavier so that's why it goes to the bottom. The higher the pressure is, the further it will fly. I think that tail made it a little heavy. It didn't go quite as far, huh?
Causal Invitation	Why do you think they sink to the bottom? Why is it floating? How are you going to make it fly?
(Other Causal Talk)	Which ones do you think will sink? What happens if you put it that way? The ones on the bottom are heaviest. Were you adjusting the little knob over there before? You think we should try a smaller tail? Is it aimed okay? That one sinks. See, it goes straight to the bottom.

Table 3

Percent of Missing Data and Reasons for Missingness

Task	% Missing	Top 3 reasons for missingness
NIH-ECB		
PVT	0.65	Technical (*n* = 2)
FL	24.84	Attrition (*n* = 22), Behavior (*n* = 7), Failed training (*n* = 5)
DCCS	32.68	Attrition (*n* = 30), Failed training (*n* = 8), Behavior (*n* = 8)
PS	39.87	Attrition (*n* = 27), Technical (*n* = 21), Behavior (*n* = 1)
Home Science	3.92	Incomplete (*n* = 6)
Causal Stance		
Picture Inquiry	41.83	No questions (*n* = 37), Technical (*n* = 12), Attrition (*n* = 10)
Object Inquiry	54.90	Technical (*n* = 35), Attrition (*n* = 28), No questions (*n* = 16)
Preference	50.98	Procedural drift (*n* = 53), Technical (*n* = 8), Behavior (*n* = 7)
Lens on Science	2.61	Technical (*n* = 4)
Parent Causal Talk		
Museum	8.50	Technical (*n* = 7), Insufficient length (*n* = 6)
Lab	12.42	Attrition (*n* = 10), Technical (*n* = 9)

Note. NIH-ECB = NIH Toolbox Early Cognition Battery. PVT = Picture Vocabulary Test; FL = Flanker Inhibitory Control and Attention Test, DCCS = Dimensional Change Card Sort Test; PS = Picture Sequence Memory Test.

Table 4

Summary of Intercorrelations, Means, and Standard Deviations

Measure	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*M*	*SD*
1. Lens on Science	–							0.37	1.00
2. Causal Stance	.43**	–						0.41	0.24
3. Home Science	.17*	.18	–					12.34	3.72
4. NIH-ECB	.52**	.35**	.32**	–				103.63	17.59
5. Parent Causal Talk	.11	.30**	.22*	.07	–			0.72	0.16
6. Parent Causal Explanations	.04	-.01	.22**	-.08	.26**	–		0.13	0.12
7. Parent Causal Invitations	.23**	.10	.18*	.11	.26**	.09	–	0.09	0.10

** $p < .01$. *$p < .05$.
Note. NIH-ECB = NIH Toolbox Early Cognition Battery.

Table 5

Parameter Estimates from Multiple Regression Analysis Predicting Causal Stance

	Unstandardized		Standardized			
Predictor	B	*SE*	β	*sr*	*t*	*p*
(Intercept)	-0.34	0.19	.00		-1.82	.070
Parent Causal Talk	0.40	0.15	.27	.26	2.65	.008
NIH-ECB	0.00	0.00	.32	.30	2.52	.012
Home Science Exposure	0.00	0.01	.02	.02	0.13	.900

Note. NIH-ECB = NIH Toolbox Early Cognition Battery; *sr* = semipartial (part) correlation.

Table 6

Parameter Estimates from Multiple Regression Analysis Predicting Scientific Literacy

	Unstandardized		Standardized			
Predictor	B	*SE*	β	*sr*	*t*	*p*
(Intercept)	-2.71	0.50	.00		-5.42	<.001
Parent Causal Invitations	1.72	0.76	.18	.18	2.25	.025
NIH-ECB	0.03	0.01	.51	.48	5.67	<.001
Home Science Exposure	-0.01	0.02	-.03	-.02	-0.33	.743

Note. NIH-ECB = NIH Toolbox Early Cognition Battery; *sr* = semipartial (part) correlation.