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BRIEF REPORT

Causal learning is collaborative: Examining explanation and exploration in social contexts

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Abstract Causal learning in childhood is a dynamic and collaborative process of explanation and exploration within complex physical and social environments. Understanding how children learn causal knowledge requires examining how they update beliefs about the world given novel information and studying the processes by which children learn in collaboration with caregivers, educators, and peers. The objective of this article is to review evidence for how children learn causal knowledge by explaining and exploring in collaboration with others. We review three examples of causal learning in social contexts, which elucidate how interaction with others influences causal learning. First, we consider children's explanation-seeking behaviors in the form of "why" questions. Second, we examine parents' elaboration of meaning about causal relations. Finally, we consider parents' interactive styles with children during free play, which constrains how children explore. We propose that the best way to understand children's causal learning in social context is to combine results from laboratory and natural interactive informal learning environments.

Keywords Causal reasoning · Cognitive development · Culture · Informal learning environments

Children actively seek to understand the causal structure of the world around them. Causal learning in childhood is a dynamic process of observation, explanation, and exploration within complex physical and social environments. Children's learning is not exclusively the product of processing information individually; instead, learning is inextricably embedded in social activities and practices (Cole, 1996, 2010; Gauvain & Perez, 2015; Rogoff, 2003; Vygotsky, 1962). Understanding how children learn causal knowledge requires examining how they update beliefs about the world given novel information and studying the processes by which children learn in collaboration with caregivers, educators, and peers.

The objective of this article is to review evidence for how children learn causal knowledge by explaining and exploring in collaboration with others. For the purposes of this review, we constrain *explaining* to the ways in which children elicit and generate verbal information about a set of causal relations and *exploring* to the ways in which children act on the world that generates information from others or the environment. We propose that explaining and exploring operate synergistically: Explanation serves as a mechanism for generating, constraining, and evaluating hypotheses (Legare & Lombrozo, 2014; Walker, Lombrozo, Legare, & Gopnik, 2014). Exploration serves as a mechanism for testing those hypotheses or for discovering that there is something to explain (Legare, 2014). These two processes allow children to build more sophisticated and veridical representations of the causal structure of the world around them.

Originally proposed by Vygotsky (1962), sociocultural theory contextualizes children's cognitive development (Cole, 2010; Gauvain, 2001; Lancy, Bock, & Gaskins, 2010; Rogoff, 1990; Tudge, Putnam, & Valsiner, 1991; Wertsch & Tulviste, 1992). The development and socialization of the child is an interactive process in which the young child is exposed to and active in "a community of those who share his sense of belonging to a culture" (Bruner, 1986, p. 127), creating a connection between a child's social context and

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development. Parents, adult caregivers, and peers are present and active partners in children's learning processes (Bjorklund, Hubertz, & Reubens, 2004; Callanan, Siegel, & Luce, 2007; Goodnow & Collins, 1990 Lancy, 2008; Lave & Wegner, 1991).

Given the active role of caregivers in children's development (Callanan & Jipson, 2001), understanding the development of causal learning requires examining caregiver scaffolding and socialization (Geary & Bjorklund, 2000; Harkness & Super, 1996; Keller, Voelker & Yovsi, 2005; Okagaki & Divecha, 1993). Children acquire new skills and behaviors with the aid of more competent cultural members who scaffold their learning and allow children to attain skills that are just beyond their present abilities (Vygotsky, 1962).

Examining children's cognitive development within complex social and physical contexts provides insight into their developing abilities and competencies. Children who may not be able to demonstrate the capacity to engage in a behavior of interest in a novel environment may show a mastery of the same skill in familiar environments. For example, Carraher, Carraher, and Schliemann (1985) describe this contrast when examining Brazilian street vendors use of complex mathematical techniques. Children who did not engage in higher order mathematical thinking when presented with noncontextualized math problems generated accurate solutions when they were given the same problems within the familiar context of selling merchandise.

Causal learning in context: Three examples

To understand the importance of explaining and exploring for causal learning, it is imperative to attend to the social and cultural contexts in which these activities take place. Cultures differ dramatically along a number of dimensions that are relevant to understanding parent–child interaction (Legare & Harris, 2016; Nielsen, Haun, Kärtner, & Legare, 2017). These differences include cultural values (e.g., competition, conformity, cooperation, creativity, independence), primary caregivers (e.g., parental vs. extended family and siblings), language (e.g., the ways in which different languages afford requests for information or describe evidentials), pedagogical style (e.g., didactic teaching vs. expectation of observational modeling), and parenting style (e.g., child-centered vs. adult-centered; Bolin, 2006; Clegg & Legare, 2017; Clegg, Wen, & Legare, 2017; Cole, 1990; Gaskins & Paradise, 2010; Keller, 2007). While reviewing all of these cultural differences is beyond the scope of this review, we review three examples of causal learning in social contexts, which elucidate how interaction with others influences causal learning. First, we consider children's explanation-seeking behaviors in the form of "why" questions. Second, we examine parents' elaboration of meaning about causal relations. Finally, we consider parents' interactive styles with children during free play, which constrains how children explore.

"Why" questions

Children do not learn causal knowledge only through observation and solitary interaction with the world (e.g., Harris & Koenig, 2006; Harris, Pasquini, Duke, Asscher, & Pons, 2006). Instead, children actively seek out information from others. Examining children's "why" questions provides unique insight into how children seek out causal information from more experienced members of their family and community. Research on children's "why" questions has revealed a great deal about the developmental course of children's requests for explanation, and about how children use these questions to gain better understanding of causal mechanisms. Hood and Bloom (1979) showed that by 30 months, children are productively using causal statements and "why" questions. In a diary study, Callanan and Oakes (1992) similarly found that parents of 3- through 5-year-olds reported their children's spontaneous use of meaningful "why" questions in conversation. Frazier, Gelman, and Wellman (2009) provided clear evidence that these questions are likely to be genuine requests for causal explanations rather than merely bids to keep conversation going. These children were more likely to continue to ask versions of the same question when given a nonexplanatory reply but were more likely to ask a new follow-up question when given an explanatory answer.

Notably, there are individual differences in the extent to which caregivers and educators encourage explanatory behavior on the part of the child, which may potentially influence the amount of explanatory behavior children generate, and in turn what children learn (Clegg & Legare, 2017). The extent to which the use of "why" questions is culturally variable, however, is contentious. Tizard, Hughes, Carmichael, and Pinkerton (1983) found that a group of 4-year-old girls in the UK asked more explanatory questions at home than at school, and that this difference was more pronounced for working-class girls. In a study of Mexican-heritage families of diverse schooling backgrounds living in the U.S., children asked as many "why" questions as the middle-income children in the Callanan and Oakes (1992) study (Solis & Callanan, 2016). This included two groups of Mexican immigrant families, one group in which parents had an average of 7 years of schooling and held working-class or migrant jobs, and one group in which parents had completed at least 12 years of schooling. Children in these immigrant families asked as many questions, and even many of the same questions, as middle-income European American children.

In contrast, Gauvain, Munroe, and Beebe (2013) reported cultural differences in children's "why" questions. They analyzed archival language data from four non-Western cultural

communities collected in the late 1970s and found that while information-seeking questions were asked as often as in Western communities, the subset of explanation-seeking questions were asked much less often. While the methods used in the Gauvain et al. (2013) study are quite different from those of the other studies cited, their findings raise important questions about cultural diversity in practices such as asking "why" questions.

"Why" questions constitute a social practice of inquiry about causes and effects in everyday settings that seem to be part of life for many young children. Unlike many laboratory settings, children's spontaneous questions provide unique insight into the aspects of the world around them for which children seek causal explanations.

Elaborating parent–child talk for causal learning

Children's explanations reveal their causal knowledge (Hickling & Wellman, 2001; Keil & Wilson, 2000; Legare, Wellman, & Gelman, 2009; Sobel, 2004; Wellman & Liu, 2007). The process of generating explanations assists children in interpreting observed data (E. B. Bonawitz, van Schijndel, Friel, & Schulz, 2012). Generating explanations facilitates children's acquisition of knowledge or novel inference across a variety of learning environments (Amsterlaw & Wellman, 2006; Chi, 2000; Chi, DeLeeuw, Chiu, & LaVancher, 1994; Crowley & Siegler, 1999; Legare & Lombrozo, 2014; Rittle-Johnson, Saylor, & Swygert, 2008). Such processes are critical for constructing knowledge (Cimpian & Petro, 2014; Keil, 2006; Wellman, 2011). Indeed, some have even gone so far as to argue that the desire to generate explanations is the motivating force behind all forms of learning (e.g., Brewer, Chinn, & Samarapungavan, 1998; Gopnik, 1998). Explaining also allows children to articulate new hypotheses for events that might be different from their current state of knowledge (Legare & Gelman, 2014; Legare, Gelman, & Wellman, 2010; Walker, Lombrozo, Williams, Rafferty, & Gopnik, 2017). Encouraging children to explain inconsistency may serve as a critical mechanism for integrating and reconciling discordant or ambiguous information with existing theories and may reduce engagement in theory-preserving strategies like ignoring discordant data (Legare, 2012, 2014).

Like children, parents generate a substantial amount of causal language. There is a large body of work suggesting that the "elaborativeness" of parents' talk with their children is correlated with children's recall of events (Fivush, Haden, & Reese, 2006). Fivush and her colleagues initially defined elaborative talk with regard to elaborations in narrative reminiscing. More recently, Haden and her colleagues define elaborative talk about science topics in museum contexts as involving the use of *wh*- questions and associations with prior experiences or knowledge (e.g., Benjamin, Haden, & Wilkerson, 2010; Haden, 2010; Jant, Haden, Uttal, & Babcock, 2014). Elaborativeness in parent talk has been found to correlate with children's memory as well as with their understanding of science-related content, particularly specific kinds of physical causal relations. While not the same as causal explanation, elaborative talk also provides a framing for children's experiences.

Other studies of parent–child explanatory conversations in museum settings suggest that parents' explanations can provide framing that may give children different ways to interpret the activities that they are engaged in (e.g., Crowley, Callanan, Tenenbaum, & Allen, 2001; Tare, French, Frazier, Diamond, & Evans, 2011). Fender and Crowley (2007) found that children whose parents explained to them were more likely to develop a conceptual understanding of a museum exhibit than children whose parents did not provide any explanation.

There is also substantial cultural variation in such parent–child interaction. Parents with varied schooling background or attitudes about the nature of knowledge tend to talk differently to their children (Luce, Callanan, & Smilovic, 2013; Valle, 2006). For example, Valle (2006) found that parents from engineering and science backgrounds focused more on scientific evidence about conflicting claims on topics such as climate change than did parents from other backgrounds. In museum settings, visitors' agendas have been found to correlate with their learning (Falk, Moussouri, & Coulson, 1998). Tenenbaum and Callanan (2008) showed that Mexican immigrant parents generated fewer explanations than Mexican American parents in a museum setting, and yet the two groups explained equally in a museum-like task at home. Such a difference potentially reflects the novelty of the museum setting for the immigrant families (many of whom had never been to a museum before). All of these factors can contribute to the way in which children generate their own explanations, as they indicate different cultural norms that might encourage different forms of explaining.

Parent–child exploration

Much in the same way children ask "why" questions to solicit information out of others, they interact with others as a way of gathering more information about the world. Such information allows children not only to learn about specific causal relations but also to coconstruct meaning and be more part of a culture. Exploration then can be seen as the attempt to acquire new knowledge or promote new social interaction through action on the environment. Thus, exploration should not be studied exclusively in the context of solo learning.

There is evidence that children in the U.S. explore for longer periods of time when given ambiguous evidence (E. B. Bonawitz et al., 2010; Gweon, Pelton, Konopka, & Schulz, 2014; Jara-Ettinger, Gweon, Tenenbaum, & Schulz, 2015; Stahl & Feigensen, 2015). These children also explore more systematically when faced with uncertain causal relations as

opposed to deterministic ones (Cook, Goodman & Schulz, 2011; Schulz & Bonawitz, 2007). Exploration might be a way of collecting evidence about ambiguous or more complex hypotheses so that children can better understand the world.

Research with adults (Lagnado & Sloman, 2004; Sobel & Kushnir, 2006) and children demonstrates that we may learn more effectively from observing the results of the efficacy of our own actions as opposed to observing others generate the same data in a guided, structured environment (Baldwin, Markman, & Melartin, 1993; Bonawitz et al., 2012; Gerson & Woodward, 2014; Kushnir & Gopnik, 2005; Needham, 2009; Schulz, Gopnik, & Glymour, 2007). The benefits of learning from one's own actions are most prominent when children discover novel information, as opposed to observing efficacy they have already seen (Sobel & Sommerville, 2010; Sommerville, Woodward, & Needham, 2005). This learning benefit may be due to having access to the rationales behind one's actions. When given those rationales, preschoolers learn effectively from others' actions (Sobel & Sommerville, 2009).

This kind of exploratory behavior is also related to discovery learning. Bruner (1961) emphasized that students who discover information for themselves are more motivated to achieve educational goals and more likely to remember learned information. Students learn better by discovering causal structure through guided activity-based exercises rather than being directly told what to do or being given unstructured activity (Bredderman, 1983; Kittel, 1957; Shulman & Keislar, 1968). The former type of activity allows children to learn novel information based on scaffolding activities from others (particularly teachers) instead of simply being told information without context or direction. Neither guided exploration nor direct instruction is socially independent, but there is also evidence that free, unguided exploration is potentially less effective than either (Mayer, 2004). Particularly for young children, exploratory play may be a crucial context for cognitive development (Singer, Golinkoff, & Hirsh-Pasek, 2006; Weisberg, Hirsh-Pasek, Golinkoff, Kittredge, & Klahr, 2016).

All of these results point to the importance of collaborative exploration for learning. In informal learning environments, some research has shown that the ways that children explore their environment can be influenced in subtle ways by the presence of and the actions of other people. For example, in a study of parent–child engagement at a museum exhibit (a zoetrope), Crowley, Callanan, Jipson et al. (2001) found that when parents were present, children were more likely to engage in exploration of all of the relevant components of the exhibit. Parents seemed to guide their children's exploration in subtle ways that led to better understanding of the phenomenon. Other research has investigated the ways that parents influence their children's exploration in different types of museum exhibits (Fung & Callanan, 2013; Van Schijndel, Franse, & Raijmakers, 2010). These findings seem relevant to the recent work showing that guided play leads to better learning than open-ended play (Weisberg, Hirsh-Pasek, & Golinkoff, 2013). As with most of the previous research on this topic, the families studied were from largely middle-income European American backgrounds, so it is important to avoid assumptions about this style of interaction being normative (Rogoff, 2003).

Indeed, there is cultural variation in parents' styles of interacting with children. Whereas middle-class U.S. mothers use a great deal of verbal explanation with their children, mothers from rural Guatemala and Mexico expect their children to learn through nonverbal means, including keen observation (Silva, Correa-Chávez, & Rogoff, 2010). Parents' engagement with exploration and play varies across cultures as well (Gaskins, 2008), and their definitions of play contrast with those of experts (Fisher, Hirsh-Pasek, Golinkoff, & Gryfe, 2008). Gaskins (2008) explored parents' "ethnotheories" about play and found that European American, African American, and Latino parents varied considerably in their views about whether play is important for learning and whether parents should play with their children; these views also related to how parents engaged with children in the museum setting. One must go beyond studying Western middle-class populations because the same situation may hold different meaning for families from diverse cultural communities (Gaskins, 2008). Future research is needed to examine the extent to which children's causal learning differs based on cultural variation in parent–child interaction.

Conclusions and future directions

Informal learning environments, such as children's museums and science centers, provide a unique opportunity to study the social context of children's explanation and exploration (Sobel & Jipson, 2016). Data from laboratory-based studies have demonstrated that young children have sophisticated capacities to both explain and explore; however, the extent to which these capacities translate to such informal learning environments is understudied. For example, the literature examining children's scientific reasoning suggests that preschoolers do not consistently engage in systematic hypothesis testing, nor do they demonstrate consistent understanding of the relation between data and conclusions or how to design unconfounded tests of causal relations (Dean & Kuhn, 2007; Klahr & Nigam, 2004; Schauble, 1996). Those who create and study informal learning environments often focus on creating open-ended activities where children and adults can explore scientific understandings through hands-on exploring and collaborative construction of explanations (Allen, 2004; Gutwill & Allen, 2010). Cultural differences are also crucial to investigate here for the same reason as above, as families from different backgrounds might approach open-ended activities quite differently, which may support multiple different pathways to causal learning.

More research is needed to examine how children from diverse cultural backgrounds learn causal knowledge from museum exhibits and other activities. Parents' science explanations predict certain aspects of children's causal learning (Fender & Crowley, 2007), but such findings need to be expanded to more diverse cultural groups and replicated and extended to other contexts. Future research should also systematically consider variation in the conditions under which parents from different cultural backgrounds choose to encourage children's scientific reasoning, a topic of inquiry with major implications for communities currently underrepresented in STEM fields. These cultural differences might promote different attitudes within children for explaining and exploring, which in turn may foster different avenues for causal learning.

Understanding how children engage in causal learning through explaining and exploring does not just involve the act of children processing data from the environment and integrating that information with their prior knowledge. Children are influenced by the context in which information is presented and the communicative acts parents, teachers, and peers use to convey information, all of which are culturally mediated (Callanan, Shrager, & Moore, 1995). For researchers in children's causal learning who have argued for "rational constructivism," such cultural influences could be seen as "priors"—pieces of prior knowledge that constrain hypotheses and inferences (Xu & Kushnir, 2012). But this is an obviously unsatisfying explanation. Priors are fixed, while the contextual and cultural influences we have described are dynamic. Moreover, priors are based on the individual—children as learners—as opposed to the idea that children construct meaning from their interactions and the nature of that construction is different depending on individual variations in interactive style.

We propose that the best way to understand children's causal learning is to combine results from laboratory and natural interactive environments. Conducting research in informal learning settings (like museums) is not a replacement for research done in the lab but instead, provides unique insight into the social context of children's learning because they are natural learning spaces for many families (Callanan, 2012; Callanan, Martin, & Luce, 2016; Legare, Gose, & Guess, 2016; Sobel, Letourneau, & Meisner, 2016). There are challenges in tackling the complexity of this work; however, our experience is that working through these challenges has great potential to lead us toward a more comprehensive understanding of children's causal learning.

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