

To appear in Lucas Butler, Samuel Ronfard, & Kathleen Coriveau (Eds.), *The Questioning Child: Insights from Psychology & Education*. Cambridge University Press.

## **Asking "why?" and "what if?": The influence of questions on children's inferences**

Caren M. Walker (University of California, San Diego)  
& Angela Nyhout (University of Toronto)

### **1. Introduction**

In learning about the world, we often form inferences on the basis of sparse data. Despite this challenge, children are prolific learners. Very young children form, test, and rationally revise hypotheses in building informal theories in a variety of domains (Carey, 1985; Gopnik & Meltzoff, 1997; Keil, 1992; Wellman & Gelman, 1992). Preschoolers use data from interventions to infer causal structure (Schulz, Gopnik, & Glymour, 2007) and use patterns of dependence to learn about causes in various domains, even when the evidence they observe conflicts with their prior knowledge (Gopnik, Sobel, Schulz, & Glymour, 2001; Schulz & Gopnik, 2004). Toddlers interpret patterns of data to infer unobserved causes (Kushnir, Gopnik, Schulz, & Danks, 2003) and even abstract relations (Walker & Gopnik, 2014; 2017). In this chapter, we describe a growing body of research that demonstrates the efficacy of specific questions in supporting children's ability to access these intuitive reasoning skills and apply them to tasks involving sophisticated causal and scientific thinking.

In particular, we will consider three candidate questions that are likely to promote learning and inference in explicit causal reasoning tasks: explanation ("why?" questions), multiple explanation ("why else?" questions), and counterfactuals ("what if?" questions). We describe the distinct mechanisms by which each of these questions likely results in unique types of inferences, and review existing empirical evidence from both children and adults providing evidence for their effectiveness. We argue that the particular question posed carries selective effects on a learner's inferences, depending upon the evidence available, the state of their prior knowledge, and the relation of that prior knowledge to the true state of the world.

In exploring the role of specific questions for causal learning in early childhood, we begin with a brief review of the well-established research on the efficacy of prompts for explanation, focusing on the developmental literature. We then offer a novel proposal, drawing on the adult research, that engaging children in the evaluation of alternative outcomes via prompting for multiple explanations or engagement with counterfactuals may provide a different avenue for fostering distinct sets of causal reasoning skills. Finally, we turn to a discussion of the relation between the content and process of children's reasoning in response to these questions, and end with some suggestions for future research.

### **2. Explanation: Asking "Why?"**

#### ***2.1. Why are prompts to explain effective?***

Explanation questions – questions of the form, “why did *X* happen?” – have been extensively studied in the developmental literature to date. The benefits of self-explanation have been observed in a broad range of learners, from preschoolers to adults, and across a variety of knowledge domains and educational contexts, including both formal and informal learning environments (e.g., Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, De Leeuw, Chiu, & LaVancher, 1994; Crowley & Siegler, 1999; Legare & Lombrozo, 2014; Siegler, 2002; Walker, Lombrozo, Legare, & Gopnik, 2014). Here we will focus on developmental findings that have examined the effects of generating explanations on early learning in young children.

First, some accounts suggest that “why?” questions engage domain general processes that are not necessarily unique to explanation. For example, the act of generating an explanation has been proposed to increase attention and task engagement (Siegler, 2002). Others have suggested that cognitive benefits result from the fact that explaining is a goal-directed (Nelson, 1973) or constructive process, in which the learner is asked to go beyond the information that is explicitly provided (Chi, 2009). Explanations have also been suggested to help learners to identify gaps or inconsistencies in their existing knowledge (Chi, 2000). On each of these views, non-explanation tasks that serve to engage the same mechanisms should similarly enhance learning.

More recent accounts have instead emphasized the unique and selective effects of explanation, which carry advantages over and above those conferred by other learning strategies. In particular, the act of explaining appears to recruit attention to specific types of hypotheses that capture the characteristics of *good* explanations – those that are broad (Lombrozo, 2012; Walker, Lombrozo, Williams, Rafferty, & Gopnik, 2016; Williams & Lombrozo, 2010; 2013), generalizable (Legare, 2012; Walker et al., 2014; Walker & Lombrozo, 2017), and simple (Bonawitz & Lombrozo, 2012; Walker, Bonawitz, & Lombrozo, 2017). According to this view, explanation serves to constrain learning and inference, leading the learner to privilege certain hypotheses, even at the expense of others.

In line with this proposal, children who are asked to explain during learning are more likely to privilege a hypothesis that accounts for the greatest proportion of the data observed. For example, Walker and colleagues (2016) showed 5-year-old children patterns of evidence (blocks activating a novel toy) that was compatible with two candidate causal hypotheses, and varied the level of consistency of each hypothesis with their prior beliefs. In a first study, children observed the causal efficacy of blocks that varied along two dimensions that were matched in terms of prior knowledge: one dimension (e.g., the top color) covaried perfectly with the machine’s activation, while the second dimension (e.g., the front color) co-occurred with the effect 75% of the time. When children’s prior beliefs about the efficacy of each hypothesis were matched, those who explained were more likely than children in a control group to favor the hypothesis with perfect covariation.

Next, children were presented with evidence that was equally consistent with the two candidate hypotheses—block color and block size—which both perfectly covaried with the effect. However, pilot data had indicated that children favored block size as the more likely causal mechanism. In this case, when the two hypotheses were matched in terms of the number of observations, children who explained favored the hypothesis most compatible with their prior

belief (size) than controls. In a final study, prior belief (size), which accounted for 75% of the data, was pit against current observations (color), which accounted for 100% of the data. In this case, explainers were more likely than controls to favor the 75% size hypothesis, consistent with their prior beliefs, even though this hypothesis accounted for fewer observations in the current context. Thus, children who explained tended to privilege the hypothesis with the broadest *scope*: the hypothesis that is consistent with their prior belief and the current data. Similar results have also been found with adults (e.g., Williams & Lombrozo, 2010, 2013; Williams, Lombrozo, & Rehder, 2013).

Relatedly, Walker and colleagues (2014) found that explaining led children to form generalizations on the basis of inductively-rich properties of objects (i.e., those properties that are likely to be informative for future cases). Specifically, preschoolers who explained were more likely to override salient perceptual information to make inferences about objects' hidden properties on the basis of common causal affordances. Using a causal learning task, preschoolers observed a series of objects that either activated or failed to activate a toy. Children were then shown a target block that activated the toy, a perceptually-matched block that did not, and a causally-matched block that activated the toy, but was perceptually-dissimilar to the target block. Children were asked to either explain *why* or report *whether* each block made the toy activate. The experimenter then revealed that the target block contained a hidden internal part, and asked the child to select which of the other two blocks – the perceptual match or causal match – shared the same internal part. Children who had *explained* the outcome were significantly more likely to select the causally-matched block – generalizing according to the block's shared causal status – than children who were asked to *report* on the outcome. In a second study, children who explained were also more likely to extend a category label on the basis of the objects' shared causal status. When told that the target block was a “blicket,” and asked which other block was also a blicket, explainers were more likely to select the causal match over the perceptual match than children in the control condition. A final study revealed that these effects likely resulted from children's increased attention to a cluster of correlated, inductively-rich properties (causality, category labels, and internal parts), which selectively impaired their memory for an uncorrelated, but highly salient perceptual feature (i.e., stickers placed on each object).

This same tendency for explainers to privilege information about causal mechanisms at the expense of non-causal, perceptually-salient properties has been reported in other contexts as well (Legare & Lombrozo, 2014). For example, Legare and Lombrozo (2014) familiarized preschool-aged children with a novel toy composed of interlocking gears and cranks of varying sizes and colors, which was designed to cause a fan to turn. Children were asked to explain how the toy worked, or to engage in a control activity (observing or describing). One of the gears was then surreptitiously removed. Children who had generated explanations were more likely to select a functionally correct replacement gear that was perceptually dissimilar from the original when compared with controls. They were also more likely to successfully construct a novel (functional) gear arrangement on their own. On the other hand, the non-explainers were better able to recall salient non-causal information (i.e., the color of the missing gear). Interestingly, these results were observed regardless of the specific prompts provided; those in the control condition who *spontaneously* explained showed similar effects.

In addition to selectively boosting attention to hypotheses that are broad and generalizable, explanation has also been shown to increase children’s tendency to favor *simplicity* (i.e., privileging a single, unifying cause over multiple causes). Walker and colleagues (2017) presented 4-, 5-, and 6-year-olds with a garden consisting of four quadrants of plants, two “healthy” and two “unhealthy,” and directed them to consider the two plots of “unhealthy” plants. The evidence was consistent with a single common cause (both were planted in the same type of soil) or two independent causes (one plot had a broken sprinkler, the other lacked sunlight). Children were prompted to explain *why* or report *whether* the plants were sick in each quadrant. After being presented with a novel garden at test, children were asked to predict which plants were unhealthy. Five-year-olds who had explained favored the simpler, common cause at a higher rate than those who had reported, indicating that explanation heightens children’s sensitivity to simplicity as a basis for favoring one hypothesis over another. Interestingly, however, this condition difference did not extend to 4- or 6-year-olds: 4-year-olds showed no preference for the simpler hypothesis in either condition, and 6-year-olds preferred the simpler hypothesis in both conditions. The authors proposed that a combination of factors, including effects of prior knowledge and other cognitive biases that may account for these developmental differences.

Taken together, each of the cases presented above could also be interpreted as evidence that explanation leads learners to favor more *abstract* hypotheses in the service of generalization. Indeed, several previous accounts of the effects of explanation suggest a direct or indirect relation to abstraction (e.g., Lombrozo & Carey, 2006). For example, given that the instance being explained is related to a more general framework (Lombrozo, 2006, 2012; Wellman & Liu, 2007; Williams & Lombrozo, 2010, 2013), explanation may draw the learner’s attention towards more abstract features (Walker & Lombrozo, 2017). Several recent studies directly assessing this interpretation have provided some support for this claim (e.g., Walker & Lombrozo, 2017; Walker, Bridgers, & Gopnik, 2016). First, Walker and colleagues (2016) found that generating explanations in a causal learning paradigm facilitated 3- and 4-year-olds in learning and applying abstract relational rules (i.e., “same” and “different”). Later, Walker and Lombrozo (2017) reported that prompting 5- and 6-year-olds to explain during a storybook reading bolstered their ability to identify and extend abstract moral themes from fictional stories—a notoriously challenging task for young children (e.g., Narvaez, Gleason, Mitchell, & Bentley, 1999). In this study, an experimenter read storybooks designed to convey a particular moral theme (e.g., tolerance), periodically interrupting the story to ask children to either *explain* why an event occurred or *report* whether an event had occurred. Even though the explanation prompts did not specifically direct children’s attention to the moral theme, those who were prompted to explain were more likely to recognize and generalize the theme across a range of dependent measures. In contrast, children who were asked to report were more likely to respond on the basis of surface features and similarities in stories, in line with previous research.

## 2.2. *Summary and limitations of explanation*

Together, the studies reviewed above demonstrate the *selective* effects of explanation, though as noted above, these effects are not universally beneficial. First, when children are prompted to explain how a novel toy works, they are more likely to learn and generalize on the basis of inductively-rich (e.g., causal, categorical, internal, mechanistic) properties, at the expense of

learning and remembering perceptual information. Second, when presented with competing hypotheses, children who explain tend to favor simpler over complex hypotheses, as well as those with greater scope (often drawing on prior knowledge). In some cases, this tendency may come at the expense of identifying the correct hypotheses when it conflicts with prior beliefs, accounts for fewer observations, or posits multiple independent causes.

Research with adults has similarly demonstrated that prompts to explain can lead learners to *overgeneralize* at times, by identifying broad patterns and ignoring exceptions or counterexamples that may be present in the data (Williams et al., 2013). Explanation has also been shown to lead adults to privilege conceptual learning at the expense of procedural learning (Berthold, Röder, Knörzer, Kessler, & Renkl, 2011), and to lead school-aged children to focus on information about causal mechanisms, overlooking potentially relevant covariation patterns (Kuhn & Katz, 2009). We can conclude, therefore, that while explanation affords clear benefits when the primary learning goal includes attention to abstract features and the formation of broad generalizations, it is unlikely to confer these same benefits in other learning contexts. As we will argue in the following sections, some of these undesirable effects might be mitigated by relying on different types of questions, including requests for *multiple* explanations or prompts to consider counterfactual alternatives.

### 3. Multiple Explanation: Asking “Why else?”

Patterns of data often afford more than one plausible explanation. Although prompting children (and adults) to explain the evidence they observe typically leads them to privilege broad generalizations (Walker et al., 2016; 2017), it is often the case that more than one hypothesis fits this description, or that a narrower hypothesis may better account for the data. After generating an initial explanation, searching for additional explanations may therefore help the learner to better localize the best fit hypothesis. Consistent with this idea, experiments in which *multiple* requests for an explanation are provided have resulted in debiased learning and reasoning in adults.

#### 3.1. Why are multiple prompts to explain effective?

In line with Kahneman and Tversky’s (1982) simulation heuristic, researchers have proposed that consideration of multiple alternatives leads individuals to adopt a “mental simulation mindset” (Fischhoff, 1982; Galinsky & Moskowitz, 2000; Hirt & Markman, 1995; Hirt, Kardes, & Markman, 2004; Koehler, 1991). This proposal was based on the observation that adults who generate a *single* explanation, especially when explaining social phenomena, show a number of biases in subsequent prediction and interpretation of related evidence (e.g., Anderson, Lepper, & Ross, 1980; Ross, Lepper, Strack, & Steinmetz, 1977). According to Koehler (1991), these individuals tend to adopt a conditional reference frame under which a focal hypothesis is assumed to be true, and this frame is then used as a lens through which the learner interprets relevant evidence. Considering counter-explanations or multiple explanations was therefore proposed to “break this inertia,” causing the learner to shift away from this single, focal hypothesis to consider a range of possibilities (Hirt & Markman, 1995). Empirical evidence in support of this view has demonstrated that adults who are asked to produce *multiple* explanations show a corresponding attenuation in various types of biased reasoning, including biases in

prediction (Hirt et al., 2004; Hirt & Markman, 1995) and hindsight bias (Sanna, Schwarz, & Stocker, 2002; Sanna & Schwarz, 2003).

Attempts to localize the mechanism underlying these effects led Hirt and Markman (1995) to develop two distinct proposals, which are both (appropriately) outlined in the same paper. First, they considered the possibility that generating multiple explanations facilitates easier access to arguments in support of the *specific* explanations they have generated, by way of the availability heuristic. Further, by entertaining more than one explanation, individuals may also express increased uncertainty about the likelihood of each of these specific alternatives, leading to decreased bias in a focal hypothesis. Next, they proposed an alternate process: that multiple explanations may invoke a domain-*general* “mindset” in which the contents and focus of each explanation need not be task-specific. In support of this second proposal, they found that individuals who explained a specific outcome (e.g., a win by the Red Sox) showed an explanation bias – increased confidence in the explained outcome – relative to individuals who also explained alternate outcomes (e.g., a win by the Blue Jays) (Hirt & Markman, 1995; Lord, Lepper, & Preston, 1984). On the other hand, individuals who generated multiple explanations showed debiased reasoning, even when the explanations were about unrelated events (e.g., winner of the best sitcom) (Hirt et al., 2004), indicating a *general* openness to alternatives. However, the longevity of this effect remains unknown.

In addition to debiasing adults’ predictions, multiple explanations have also been credited with attenuating the effects of the hindsight bias (Fischhoff, 1982; Koriat, Lichtenstein, & Fischhoff 1980), in which individuals consistently overestimate their ability to have predicted events that have already occurred (Fischhoff, 1975). For example, adult reasoners often view the outcome of an election as inevitable and predictable, even when all indications prior to election night suggest that it would be a tight race. In a series of studies, Sanna and colleagues asked participants to explain alternate outcomes to a war, a college football game, or an election (Sanna et al., 2002; Sanna & Schwarz, 2003). They found that those individuals who generated *two* alternatives were less likely to show hindsight bias across the board.

As in the research on the effects of requests for a single explanation, requests for multiple explanations may also include certain drawbacks. In particular, when adults are asked to generate *too many* explanations in a given task, their reasoning is no less biased than baseline (Hirt et al., 2004; Sanna et al., 2002). When generating explanations, individuals tend to evaluate their plausibility – not only in terms of their content – but also in terms of the *ease* with which they bring examples to mind (i.e., accessibility experiences; Schwarz, 1998; Schwarz & Vaughn, 2002). Therefore, if generating alternatives is perceived as difficult, as is typically the case when individuals are asked to generate several explanations, they may end up concluding that the initial explanation or hypothesis was the correct one after all. Similarly, when individuals are asked to generate an *implausible* explanation (e.g., a win by a poorly performing team), their judgments also tend to revert back to the original, focal hypothesis (Hirt & Markman, 1995).

### ***3.2 When might multiple explanations support learning and inference in childhood?***

To our knowledge, previous research has not directly examined the use of multiple explanation prompts to debias reasoning in children. However, the ability to generate multiple explanations is

likely supported by the same suite of cognitive abilities that underlies the representation of multiple possibilities (Hirt et al., 2004; Horobin & Acredolo, 1989). Although some have suggested that acknowledging the presence of more than one possibility poses a significant challenge for young children (e.g., Beck, Robinson, Carroll, & Apperly, 2006; Horobin & Acredolo, 1989), others have forwarded the opposite claim, demonstrating that they may engage with alternate possibilities more readily than older children and adults (Lucas, Bridgers, Griffiths, & Gopnik, 2014; German & Defeyter, 2000).

Like adults, children appear to express a number of biases in prediction, explanation, and hypothesis-testing. For example, children begin to express the fundamental attribution error as early as 6 years of age, tending to prefer trait explanations over situational explanations for an individual's behavior (Seiver, Gopnik, & Goodman, 2013). Children also express a bias towards teleological explanations when reasoning both about artifacts and natural kinds (Kelemen, 1999), as well as essentialist explanations when reasoning about biological and psychological events (Gelman, 2003; Taylor, 1996; Taylor, Rhodes, & Gelman, 2009). We are therefore currently exploring whether asking children to generate multiple explanations for an observed phenomenon could help increase their consideration of alternate possibilities and decrease fixation on an initial explanation (e.g., that someone is exhibiting a behavior because of their membership in a particular group), which can have pernicious social consequences (e.g., Rhodes, Leslie, Saunders, Dunham, & Cimpian, 2018).

Relatedly, fixating on an initial hypothesis has also been shown to lead to biases in children's evidence-seeking and hypothesis-testing. Several studies indicate that when children have a strong belief in a hypothesis (Penner & Klahr, 1996) or are motivated to produce a specific outcome (Zimmerman & Glaser, 2001), they tend to engage in biased hypothesis-testing, seeking to confirm, rather than disconfirm their initial hypothesis (Kuhn & Phelps, 1982). If their commitment to a particular hypothesis leads them to engage in hypothesis-confirmation, then asking children to generate alternate explanations could reduce this tendency (Galinsky & Moskowitz, 2000). There is at least one piece of suggestive evidence indicating that hypothesis-testing may be facilitated by exposure to *contrastive beliefs* in childhood as well. Across three experiments, Cook and Schulz (2009) found that children were better able to conduct a controlled test of a hypothesis after they heard contrasting hypotheses about which variables affect how far a ball travels on a ramp (e.g., "Bob thinks the height of the ramp matters, and Emily thinks the type of ball matters") than children in a control condition. Although children were not prompted to generate multiple explanations, a similar mechanism may underlie both instances, since those who encountered contrastive beliefs had the opportunity to consider alternatives. According to Mercier and Sperber (2011), engaging in argumentation through dialogue or group reasoning benefits reasoning via exposure to multiple explanations. Although these explanations are typically provided by others in a social context, the authors note that individual learners may be able simulate these benefits by "distance[ing] themselves from their own opinion, to consider alternatives and thereby become more objective" (pg. 72). Future research will therefore investigate the process by which self- versus other-generated beliefs and explanations might influence children's hypothesis-testing.

### ***3.3. Summary and limitations of multiple explanations***

Research with adults has found that prompting individuals to generate multiple explanations attenuates bias on various reasoning tasks, as long as individuals are not asked to generate too many alternatives (Hirt & Markman, 1995; Hirt et al., 2004; Sanna et al., 2002; Sanna & Schwarz, 2003). Here, we have outlined several proposals regarding how these findings may extend to children. First, multiple explanations could be particularly supportive in cases where children are biased towards certain types of highly salient explanations (e.g., essentialist explanations; Gelman, 2003) by prompting them to consider alternatives. Second, these prompts could serve to debias hypothesis-testing following the generation of an initial hypothesis (Kuhn & Phelps, 1982). Asking children for more than one explanation may also be preferable to requests for single explanations in at least two contexts: (1) when the initial search is biased, due to a strongly-held prior theory or interest in a particular outcome, and (2) when the true hypothesis does not conform to the explanatory virtues of simplicity, breadth, etc.

At present, the proposals we have outlined about the specific impact of multiple explanations on learning and inference in childhood remain largely speculative. Empirical work is underway (in collaboration with Dr. Patricia Ganea) to investigate whether prompts to generate multiple explanations support children's hypothesis-testing in the context of both controlled laboratory settings and ecologically-valid classroom settings. That said, there is an important methodological issue that future studies exploring the role of multiple explanations on children's inferences will have to carefully address. In particular, previous research by Gonzalez, Shafto, Bonawitz, and Gopnik (2012) indicates that the use of repeated questions in a developmental paradigm introduces a set of pedagogical inferences. In this study, preschoolers who were asked a neutral question ("Is that your final guess?") after making a selection were more likely to switch their answer when the adult speaker was perceived as knowledgeable than when she was perceived as ignorant. Children might similarly interpret an experimenter's request for a second explanation as a pedagogical cue that their first response was incorrect. Although these effects may be mitigated (Gonzalez et al., 2012), this caveat is not trivial. If future research finds that multiple explanations indeed bolster children's learning, it will be critical to discern whether this advantage is conferred by the process of engaging with alternatives or due to this pedagogical inference.

Finally, in the next section, we consider the influence of counterfactual ("what if?") questions on children's learning and inference. We propose that the process underlying the generation of multiple explanations and counterfactuals are likely quite similar: both involve considering alternatives to a focal hypothesis, explanation, or event. However, there are also important potential differences between the two. Whereas multiple explanations involve accounting for evidence or generating predictions in more than one way, counterfactuals involve *changing* a particular causal variable and reasoning about the outcomes of that change. Thus, while both question-types may guide the learner to consider alternatives, counterfactuals are predicted to have the additional benefit of supporting causal inference and scientific reasoning by mentally manipulating events in a manner that is analogous to hypothesis-testing. Additionally, because counterfactuals explicitly require the individual to consider a premise that contrasts with actual events, they may lead the learner to elevate possible hypotheses that are initially lower-probability, or even counterintuitive.

#### **4. Counterfactuals: Asking "What if?"**



Both children and adults spend a large amount of time entertaining thoughts about what did not or will not happen. This type of thought – termed *counterfactual thinking* – has been suggested to support a range of judgments and decisions (Byrne, 2016). Counterfactuals help us to understand the causes of past events, including both small scale (e.g., Spellman & Mandel, 1999) and historically-significant events (Tetlock & Belkin, 1996), to plan for the future (Epstude & Roese, 2008; Markman, McMullen, & Elizaga, 2008), and to ascribe moral judgments (e.g., Branscombe, Owen, Garstka, & Coleman, 1996). Commonly framed as conditional *if-then* statements, counterfactuals allow individuals to make a range of causal inferences from “If there was no icy patch, then I would not have fallen” to “If there was no ice age, then there would be no Yosemite Valley”.

In the following section, we suggest that entertaining counterfactual questions may help even the youngest learners to not only consider alternative hypotheses, but to identify lower-probability hypotheses that they may not have otherwise considered. Scientific progress, in particular, often relies upon radically rethinking current dogmas and challenging intuitions. Many scientific discoveries, including the discovery of germs, the realization that the Earth is round, and the theory of evolution by natural selection resulted from positing counterintuitive hypotheses. We therefore consider how engaging in counterfactual thinking might similarly guide and support children’s causal learning in the context of scientific reasoning.

However, before turning to the existing findings supporting this proposal, we should first establish a working definition of counterfactual reasoning in this context, given the lively debate surrounding the presence of these abilities in young children (e.g., Weisberg & Gopnik, 2013; Beck, 2016). For example, several previous empirical and theoretical accounts of the development of counterfactual reasoning have focused exclusively on past counterfactuals (e.g., Beck et al., 2006; Rafetseder & Perner, 2014; Roese, 1997), suggesting that this ability may not reach maturity until well into middle childhood (Beck & Riggs, 2014), or adolescence (Rafetseder, Schwitalla, & Perner, 2013). Recent research opposing these views has demonstrated that, given a sufficiently clear and simple task, children will readily engage in counterfactual reasoning as early as the preschool years (Buchsbaum, Bridgers, Weisberg, & Gopnik, 2012; Gopnik & Walker, 2013; Nyhout & Ganea, under revision; Walker, Buchsbaum, Banerjee, & Gopnik, in prep), even according to the strictest definition (e.g., Perner & Rafetseder, 2011). For our present purposes, we will leave this debate aside to take a much broader view of counterfactual reasoning, which also includes hypothetical questions about the past, present, and future, as well as conditionals.

#### **4.1. Why are counterfactual questions effective?**

In line with the research on the effectiveness of multiple explanation, research on counterfactual questions was initially separated into two broad camps: (1) those that suggest that counterfactual questions lead the learner to consider the *specific* alternative hypotheses that are generated (e.g., Byrne, 2005; Harris, German, & Mills, 1996; Roese & Olson, 1997; Tetlock & Lebow, 2001), and (2) those that suggest they prime the learner to consider alternatives more broadly (Galinsky & Moskowitz, 2000). However, an additional third camp (3) proposes that engagement with counterfactuals may have a more directed effect on *causal reasoning*, allowing the learner to

conduct imagined interventions on a causal system (Walker & Gopnik, 2013ab; Buchsbaum et al., 2012; Gopnik & Walker, 2013; Woodward, 2007). We review evidence for each of these accounts below.

In line with the first camp – that simulating counterfactuals facilitates *specific* causal inferences – research with adults has demonstrated that considering a counterfactual scenario makes the parallel causal inference more accessible (Roese & Olson, 1997; Tetlock & Lebow, 2001; for a review, see Byrne, 2005). For example, in one study, adults witnessed a simple causal event (e.g., a ball hitting a lever and a light switching on) and were then asked *causal* (“Did the ball hitting the lever make the light come on?”) and *counterfactual* questions (“If the ball had not hit the lever, would the light have come on?”) (Roese & Olson, 1997). Participants who were first asked the counterfactual question verified the causal question more quickly than those who were asked the causal question first. However, being asked the causal question first did not similarly facilitate reasoning about the counterfactual. These results suggest that counterfactual questions may support specific causal inferences. Proponents of this proposal (e.g., Byrne, 2002), argue that individuals generally only consider a single possibility when representing a causal relation (e.g., the ball hitting the lever and the light switching on), but consider two possibilities when representing a counterfactual (e.g., the ball hitting the lever, and the ball not hitting the lever).

In the second camp, researchers have proposed that, like multiple explanations, counterfactual questions invoke a “mindset” that is broadly open to alternatives, leading to generally debiased reasoning. In support of this claim, Galinsky and Moskowitz (2000) presented adult participants with a vignette about a narrow miss that has been demonstrated to induce consideration of counterfactual alternatives. After reading this vignette (or a control vignette), participants were provided with an unrelated task in which they were tasked with determining whether an individual was an introvert or an extrovert. They were told that a number of personality tests had indicated that the individual was likely an extrovert, and asked to select from a list of questions to assess whether this was correct. Those participants who had read the vignette designed to induce counterfactual thinking were significantly more likely to select items that were hypothesis *disconfirming* (e.g., “What factors make it hard for you to open up to people?”) than those who read a control vignette. Participants in the control condition were more likely to show a typical confirmation-biased pattern, selecting more items to confirm the focal hypothesis (e.g., “What do you like about parties?”). The authors concluded that the counterfactual prime invoked a general *mental simulation mindset*, leading adults to entertain the alternative hypothesis (i.e., that the individual was an introvert), which prompted them to seek the critical evidence needed to disambiguate between these possibilities. These priming effects suggest that engagement with counterfactuals need not be tied to the specific alternatives considered. Instead, consideration of *any* alternatives can be used to invoke this mindset (Galinsky & Moskowitz, 2000). This may be a particularly important feature to consider when applying these principles to influence reasoning in young children, who often struggle to produce accurate (or even relevant) verbal responses to questions that are posed.

Finally, the third camp has emphasized the nature of the relationship between causal and counterfactual reasoning: counterfactual dependence is the defining feature of causal knowledge (i.e., the statement *X causes Y* implies the counterfactual that *a change to X would lead to a change to Y*) (e.g., Gopnik & Schulz, 2007; Pearl, 2000; Schulz, Gopnik, & Glymour, 2007;

Woodward, 2003). Counterfactuals therefore act as input to causal judgments (e.g., Lewis, 1986; Mackie, 1974). When thinking counterfactually, the learner changes the value of the variable of interest and considers its downstream effects on other variables within the causal system – a process that is structurally identical to what we do in science. In this way, counterfactuals have been interpreted to serve as a form of thought experimentation or *imagined intervention* (Gopnik 2009; Sloman 2005; Gopnik & Walker, 2013ab; Walker & Gopnik, 2013; Walker et al., in prep).

#### 4.2. *When might counterfactuals support learning and inference in childhood?*

Given these diverse mechanisms, counterfactual questions likely support a range of early learning and reasoning tasks. In fact, past research has suggested that introducing counterfactual prompts in the form of pretend or fantastical scenarios facilitates early success in deductive reasoning, an otherwise challenging task for children (e.g., “Let’s pretend that fish live in trees. Tot is a fish. Does Tot live in a tree?”) (e.g., Dias & Harris, 1988; 1990; see Harris, 2000 for a review). Other prior work has suggested that encouraging children to think counterfactually leads them to engage in more sophisticated forms of causal inference (e.g., McCormack, Simms, McGourty, & Beckers, 2013). For example, when adult learners observe that cause *A* is associated with an outcome, and then observe that the combination of *A* and *B* is associated with the same outcome, they commonly block the inference that *B* is causal (De Houwer, Vandorpe, & Beckers, 2005; Dickinson, 2001). It has been argued that the reasoning process underlying this inference involves counterfactuals of the form “if *B* were causal, there would have been a stronger outcome” (Mitchell, Lovibond & Condoleon, 2005). Between the ages of 5 and 7 years, children increasingly make these adult-like inferences (McCormack, Butterfill, Hoerl, & Burns, 2009; Simms, McCormack, & Beckers, 2012), and there is some evidence that these abilities appear even earlier (Schulz & Gopnik, 2004; Sobel, Tenenbaum, & Gopnik, 2004). To explore whether counterfactual questions might facilitate the early appearance of these inferences, McCormack and colleagues (2013) introduced 5-7-year-old children to a toy robot that lit up and produced sound when given certain, causal foods. Two causal foods given in combination had an additive effect - the light and sound produced were more intense. Children were assigned to either a *counterfactual* or *factual* condition and were asked corresponding questions after observing foods given to the robot. For example, those in the counterfactual condition were asked to imagine what would have happened if a non-causal food were causal, whereas those in the *factual* condition were asked to report what had happened. At test, five-year-olds who answered counterfactual questions showed significantly higher levels of blocking than those who received factual questions, boosting their performance to a level similar to that of older children. The authors concluded that engaging children in counterfactual thinking selectively increased the likelihood that they would reason correctly about causal cues. A subsequent control study demonstrated that these effects were not due to increased engagement in the task.

In the following section, we expand upon these previous findings to describe a novel proposal (also currently being explored in collaboration with Dr. Patricia Ganea), regarding the role of counterfactuals in scaffolding the development of scientific reasoning skills. Decades of research have indicated that children struggle with many of the most critical elements of formal scientific inquiry (see Zimmerman, 2007 for a review), often manipulating multiple variables at a time (Chen & Klahr, 1999), prioritizing producing an effect over genuine discovery (Kuhn & Phelps, 1982), and engaging in biased interpretation of evidence (Amsel & Brock, 1996; Penner &

Klahr, 1996). The majority of developmental research has focused on children's ability to conduct a controlled test of a hypothesis – an ability termed the control of variables strategy (CVS) (Klahr, 2000; Kuhn, 2002; Zimmerman, 2000). Rather than engaging in correct CVS, which involves isolating a single variable and holding all others constant, elementary-aged children often manipulate multiple variables at a time, creating a confounded test of a hypothesis (Chen & Klahr, 1999; Klahr & Nigam, 2004; Schauble, 1996; Zimmerman, 2007).

We propose that since counterfactual reasoning and CVS both require isolating a single variable and reasoning about (or measuring) downstream effects, counterfactual prompts may scaffold children's early ability to conduct a controlled experiment by considering the outcomes produced by each variable under investigation. Despite theoretical accounts connecting counterfactual and scientific reasoning in children (Gopnik & Walker, 2013; Rafetseder & Perner, 2014; Walker & Gopnik, 2013; Wenzelhuemer, 2009), it is only very recently that researchers have begun to investigate this link empirically. In one study that is currently underway (Nyhout, Iannuzziello, Walker & Ganea, in prep), we find initial support for the claim that counterfactual questions support children's developing ability to conduct a controlled test of a hypothesis. After observing an adult actor correctly isolate a variable in an experimental context (i.e., examining factors related to motion on an incline), children given prompts to consider *counterfactual alternatives* are better able to subsequently conduct their own controlled experiment than controls, even when provided with a different set of variables to assess. These preliminary results are the first to suggest that counterfactual questions may directly support the control of variables strategy. In this case, counterfactual questions were task-specific: children were directed to consider alternatives about features of causal system (e.g., ramp height) they were asked to assess. Future studies will consider whether this intervention will also lead children to generalize the control of variables strategy to a novel experimental context.

In addition to prompting reflection about the potential outcomes of specific interventions, counterfactual questions may also enable the consideration of multiple, alternative hypotheses in order to select the one that is most consistent with the observed data. This may be particularly useful in cases where an individual holds a prior theory that is incompatible with the evidence. Although individuals frequently encounter data that contrast with their existing theories (Chinn & Brewer, 1998; Zimmerman, 2007), these anomalies may not be integrated into a learner's existing theory due to their failure to notice, correctly interpret, generalize, or remember this evidence (Chinn & Brewer, 1998). To give anomalous data due consideration, a learner should reason counterfactually: "*If my prior hypothesis were true, the observed evidence would not have occurred.*" However, previous research indicates that children typically do not engage this thought process spontaneously upon encountering anomalous data (Chinn & Malhotra, 2002; Chinn & Brewer, 1998). Counterfactual questions may therefore make patterns of causal contingency more explicit for these young learners.

To explore this, Engle and Walker (2018) asked whether leading children to harness their intuitive causal reasoning skills by way of counterfactuals may scaffold their ability to notice anomalies, using a task similar to the one described in section 2.1 (Walker et al., 2016, Experiment 1). To review, Walker et al (2016) found that when two candidate causes were matched in terms of their prior probability, children who explained preferred the hypothesis in which no anomalies were observed (the cause that accounted for 100% of the data). Engle and

Walker modified this paradigm to replace “why?” questions with “what if?” questions, and added an additional generalization phase in which children were asked to make predictions about a novel set of blocks. Results indicate that children who were asked a counterfactual question (e.g. “What if my block had been yellow? Would my toy have lit up, or not?”) were significantly more likely to privilege and extend the 100% cause than children who were asked to report what had actually happened (e.g., “What happened when I put this red one on top? Did my toy light up, or not?”). The authors conclude that counterfactual questions likely serve to draw attention to the presence of anomalous data. In this case, the *effects* of explanation and counterfactual prompts are similar, although the underlying mechanisms are likely to be different. Ongoing work aims to pull apart the effects of the two prompts by introducing prior knowledge. Walker et al (2014, Exp. 3) found that when the 75% candidate cause was more consistent with prior knowledge (i.e., block size), children who *explained* preferred that hypothesis, ignoring the presence of anomalous data. In contrast, preliminary data suggests that counterfactual questions support the recognition of anomalies, even in cases in which the learner holds an incompatible belief.

#### **4.3. Summary and limitations of counterfactual questions**

An emerging body of research demonstrates that counterfactual questions likely serve as useful pedagogical tools during childhood, supporting performance on a range of skills relevant to scientific reasoning, including causal inference, hypothesis testing, and anomaly detection. Because this work is still in its early stages, we cannot pinpoint the precise mechanism(s) by which counterfactual questions confer their benefits in each of these cases. As with repeated requests for explanation (see section 3.3), additional research should consider pedagogical effects of counterfactual questions, which may lead children to make assumptions about the accuracy of their knowledge. Future work should also investigate the robustness of these findings across contexts. Although the phrasing of both explanation and multiple explanation prompts are generally quite constrained (e.g., “Why did that happen?”), this is not the case with counterfactuals. In the initial developmental studies reviewed above, most counterfactual questions have focused on close departures from reality (e.g., asking the child to imagine that a block was a different color), directing attention to the causal variable. It remains an open question whether counterfactuals that do *not* point the learner towards the relevant simulation would similarly support learning. As noted previously, asking children to consider radical departures from the real world has been shown to engage logical reasoning (e.g., Dias & Harris, 1988; 1990; Harris, 2000). However, it is currently unknown whether asking children to consider distant counterfactuals would support or disrupt causal learning (e.g., Hirt & Markman, 1995; Galinsky & Moskowitz, 2000).

### **5. Conclusions and Future Directions**

In this chapter, we have reviewed theories and findings on the role of three types of questions in supporting children’s learning. These questions produce both overlapping and distinct effects on children’s inferences. Explanation questions – questions of the form, “Why did X happen?” – lead children to privilege abstract hypotheses that are broad, simple, and generalizable. However, in some contexts, a prompt to explain may lead the learner astray, causing them to discount evidence that is incompatible with their prior theories or to overlook more complex or narrow

(e.g., perceptually-based) hypotheses. When asked to generate *multiple* explanations (i.e., “Why else?”), however, individuals show an attenuation in biased reasoning on the basis of prior beliefs. Multiple explanations may therefore help children to consider alternatives and seek hypothesis-disconfirming evidence. Finally, counterfactual questions – those of the form, “What if *X* had happened?” – which guide individuals to perform mental simulations and interventions on causal models, may similarly scaffold their ability to consider and test alternatives (particularly those with lower prior probability) to an initial hypothesis. Together, these questions may serve to guide even the youngest learners to arrive at a conclusion that best fits the available evidence. Future work will also investigate how these different types of questions may complement one another to support learning and inference.

### ***5.1. Does the answer matter?***

Additional research is needed to better understand the relationships between the question posed, the answer produced, and the pattern of inferences that are supported. However, several of the findings described above provide initial evidence that the benefits of question-asking may be *separable* from the particular answer that is generated. For example, children who are prompted to explain tend to provide more mature patterns of inferences than controls, even when they fail to provide the correct explanation (e.g., Walker, et al., 2014). That is, the act of generating an explanation (i.e., the *process* of explaining) appears to impact reasoning independently of the content of the explanation they happen to produce (i.e., the *product* of explaining) (Wilkenfeld & Lombrozo, 2015). A number of proposals are available to explain these effects. For example, generating a poor or incomplete explanation may help the learner to identify gaps in their current knowledge or theory (e.g., Chi et al., 1994), triggering exploration (e.g., Legare, 2012). It is also possible that the act of explaining serves to constrain the hypotheses that are generated in the first place, restricting the learner to consider only those that support broad generalization (Walker et al., 2014; Walker et al., 2017; Walker & Lombrozo, 2017).

Similar findings also appear in the adult research examining multiple explanations and counterfactuals. In some cases, these questions are proposed to support learning and inference by invoking a mindset that is open to alternative possibilities, even those unrelated to the specific alternative that was initially considered (Galinsky & Moskowitz, 2000; Hirt et al., 2004; Hirt & Markman, 1995; Kahneman & Tversky, 1982). In other words, the cognitive effects of responding to a question are likely not entirely reducible to the benefits of identifying and producing the correct answer.

### ***5.2. More questions about questions...and future directions***

There are, of course, a variety of open questions left to be examined. Although the majority of findings reviewed above report effects of experimenter-presented prompts, self-directed questions are expected to produce parallel effects. Again, the *process* of generating a response has been proposed to be far more important than the particular context in which it appears (Legare & Lombrozo, 2014). This is good news, since there is significant value in identifying simple prompts to engage cognitive processes supporting learning and transfer that can easily be integrated in a variety of educational settings, including learning environments in which no instructor is present. That said, as noted above (sections 3.3 and 4.3), there are likely important

interactions between these findings and the presence (or absence) of pedagogical cues. In fact, a growing literature has begun to examine potential differences between pedagogical and non-pedagogical questions on reasoning (Gonzalez et al., 2012; Yu, Bonawitz, & Shafto, 2017). Although this topic is beyond the scope of the current chapter, these interactions represent an important avenue for future research.

In future work, it will also be important to further explore the scope of these effects across a variety of learning contexts, including naturalistic settings (e.g., parent-child conversations, classrooms, museums), and across knowledge domains (e.g., informal and formal biological, physical, and psychological learning and inference). To this end, we are currently working with museum partners to build a hands-on exhibit for an observational study looking at the role of counterfactual questions in children's hypothesis-testing. We will be looking at the role of these prompts in various delivery formats, including questions that are spontaneously generated by parents and children, questions that are prompted through strategically-placed signage, and pedagogical questions posed directly by museum staff.

Finally, open questions remain regarding the extent to which children *spontaneously* generate explanations and consider alternatives. This is an area of significant individual differences, and likely changes over the course the development (Walker et al., 2017). Children who frequently engage in self-explanation or who spontaneously entertain alternative possibilities may be more successful learners to begin with. The extent to which these individual differences are influenced by the sociocultural context, as well as other cognitive abilities, including verbal skills, flexible thinking, and uncertainty monitoring, will be an important focus for future work.

In sum, we have reviewed both theoretical and empirical evidence exploring the role of three types of questions in supporting distinct kinds of learning in childhood. We have argued that each of these questions is likely supported by a unique set of underlying mechanisms, and that each produces selective effects on children's causal and scientific reasoning. In all cases, however, asking questions can encourage even the youngest learners to go beyond their immediate observations to arrive at novel inferences.

## References

- Amsel, E., & Brock, S. (1996). The development of evidence evaluation skills. *Cognitive Development, 11*(4), 523-550.
- Anderson, C. A., Lepper, M. R., & Ross, L. (1980). Perseverance of social theories: The role of explanation in the persistence of discredited information. *Journal of personality and social psychology, 39*(6), 1037.
- Beck, S. R. (2016). Why what is counterfactual really matters: A response to Weisberg and Gopnik. *Cognitive Science, 40*(1), 253-256. doi: 10.1111/cogs.12235
- Beck, S. R., & Riggs, K. J. (2014). Developing thoughts about what might have been. *Child development perspectives, 8*(3), 175-179. doi: 10.1111/cdep.12082
- Beck, S. R., Robinson, E. J., Carroll, D. J., & Apperly, I. A. (2006). Children's thinking about counterfactuals and future hypotheticals as possibilities. *Child Development, 77*(2), 413-426.
- Berthold, K., Röder, H., Knörzer, D., Kessler, W., & Renkl, A. (2011). The double-edged effects

- of explanation prompts. *Computers in Human Behavior*, 27(1), 69-75.
- Bonawitz, E. B., & Lombrozo, T. (2012). Occam's rattle: Children's use of simplicity and probability to constrain inference. *Developmental psychology*, 48(4), 1156.
- Branscombe, N. R., Owen, S., Garstka, T. A., & Coleman, J. (1996). Rape and accident Counterfactuals: Who might have done otherwise and would it have changed the outcome? *Journal of Applied Social Psychology*, 26(12), 1042-1067.
- Buchsbaum, D., Bridgers, S., Weisberg, D. S., & Gopnik, A. (2012). The power of possibility: Causal learning, counterfactual reasoning, and pretend play. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 367(1599), 2202-2212.
- Byrne, R. M. (2002). Mental models and counterfactual thoughts about what might have been. *Trends in cognitive sciences*, 6(10), 426-431.
- Byrne, R. M. (2005). *The rational imagination: how people create alternatives to reality*. Cambridge, MA: MIT Press.
- Byrne, R. M. (2016). Counterfactual thought. *Annual review of psychology*, 67, 135-157.
- Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MA: MIT Press/Bradford Books.
- Chen, Z., & Klahr, D. (1999). All other things being equal: Acquisition and transfer of the control of variables strategy. *Child development*, 70(5), 1098-1120. doi:10.1111/1467-8624.00081
- Chi, M. T. (2000). Self-explaining expository texts: The dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.), *Advances in Instructional Psychology* (pp. 161-238). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Chi, M. T. (2009). Active-constructive-interactive: A conceptual framework for differentiating Learning activities. *Topics in cognitive science*, 1(1), 73-105.
- Chi, M. T., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive science*, 13(2), 145-182.
- Chi, M. T., De Leeuw, N., Chiu, M. H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive science*, 18(3), 439-477.
- Chinn, C. A., & Brewer, W. F. (1998). An empirical test of a taxonomy of responses to anomalous data in science. *Journal of research in science teaching*, 35(6), 623-654.
- Chinn, C. A., & Malhotra, B. A. (2002). Children's responses to anomalous scientific data: How is conceptual change impeded? *Journal of Educational Psychology*, 94(2), 327. doi: 10.1037//0022-0663.94.2.327
- Cook, C., & Schulz, L. (2009). "Bob thinks this but Emily thinks that": Contrastive beliefs in kindergartners' scientific reasoning. *31<sup>st</sup> Annual Proceedings of the Cognitive Science Society Conference* in Amsterdam, Netherlands.
- Crowley, K., & Siegler, R. S. (1999). Explanation and generalization in young children's strategy learning. *Child development*, 70(2), 304-316.
- De Houwer, J., Vandorpe, S., & Beckers, T. (2005). Evidence for the role of higher order reasoning processes in cue competition and other learning phenomena. *Learning & Behavior*, 33(2), 239-249.
- Dias, M. G., & Harris, P. L. (1988). The effect of make-believe play on deductive reasoning. *British Journal of Developmental Psychology*, 6(3), 207-221.
- Dias, M. G., & Harris, P. L. (1990). The influence of the imagination on reasoning by young children. *British Journal of Developmental Psychology*, 8(4), 305-318.
- Dickinson, A. (2001). The 28th Bartlett Memorial Lecture: Causal learning. An associative



- analysis. *Quarterly Journal of Experimental Psychology*, 54B, 3–25.
- Engle, J., & Walker, C.M. (2018). Considering alternatives facilitates anomaly detection in preschoolers. In N. Miyake, D. Peebles, & R. P. Cooper (Eds.), *Proceedings of the 40th Annual Conference of the Cognitive Science Society*. Madison, WI: Cognitive Science Society.
- Epstude, K., & Roese, N. J. (2008). The functional theory of counterfactual thinking. *Personality And Social Psychology Review*, 12(2), 168-192.
- Fischhoff, B. (1975). Hindsight is not equal to foresight: The effect of outcome knowledge on judgment under uncertainty. *Journal of Experimental Psychology: Human Perception and Performance*, 1(3), 288.
- Fischhoff, B. (1982). Debiasing. In D. Kahneman, P. Slovic, & A. Tversky (Eds.), *Judgment under uncertainty: Heuristics and biases*, 422-444. Cambridge, England: Cambridge University Press.
- Frosch, C.A., McCormack, T., Lagnado, D.A., Burns, P. Are causal structure and intervention judgements inextricably linked? A developmental study. *Cognitive Science*, 36, 261-285.
- Galinsky, A. D., & Moskowitz, G. B. (2000). Counterfactuals as behavioral primes: Priming the simulation heuristic and consideration of alternatives. *Journal of Experimental Social Psychology*, 36(4), 384-409.
- Gelman, S. A. (2003). *The essential child: Origins of essentialism in everyday thought*. Oxford Series in Cognitive Dev.
- German, T. P., & Defeyter, M. A. (2000). Immunity to functional fixedness in young children. *Psychonomic Bulletin & Review*, 7(4), 707-712.
- Gonzalez, A., Shafto, P., Bonawitz, E. B., & Gopnik, A. (2012). Is that your final answer? The effects of neutral queries on children's choices. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 34, No. 34).
- Gopnik, A. (2009). *The philosophical baby: What children's minds tell us about truth, love, and the meaning of life*. New York: Farrar, Straus, & Giroux.
- Gopnik, A. & Meltzoff, A. N. (1997). *Words, thoughts, and theories*. Cambridge, MA: MIT Press.
- Gopnik, A., & Schulz, L. (2007). *Causal learning: Psychology, philosophy, and computation*. Oxford University Press.
- Gopnik, A., Sobel, D. M., Schulz, L. E., & Glymour, C. (2001). Causal learning mechanisms in very young children: two-, three-, and four-year-olds infer causal relations from patterns of variation and covariation. *Developmental psychology*, 37(5), 620. doi:10.1037/0012-1649.37.5.620
- Gopnik, A., & Walker, C. M. (2013). Considering counterfactuals: The relationship between causal learning and pretend play. *American Journal of Play*, 6(1), 15-28.
- Harris, P. L. (2000). *The work of the imagination*. Blackwell Publishing.
- Harris, P.L., German, T., & Mills, C. (1996). Children's use of counterfactual thinking in causal reasoning. *Cognition*, 61(3), 233-259.
- Hirt, E. R., Kardes, F. R., & Markman, K. D. (2004). Activating a mental simulation mind-set through generation of alternatives: Implications for debiasing in related and unrelated domains. *Journal of Experimental Social Psychology*, 40(3), 374-383.
- Hirt, E. R., & Markman, K. D. (1995). Multiple explanation: A consider-an-alternative strategy for debiasing judgments. *Journal of Personality and Social Psychology*, 69(6), 1069. doi: 10.1037/0022-3514.69.6.1069

- Horobin, K., & Acredolo, C. (1989). The impact of probability judgments on reasoning about multiple possibilities. *Child Development*, 183-200.
- Inhelder, B. and Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence* (A. Parsons & S. Milgram, Trans.). New York, NY: Basic Books. (Original work published 1955).
- Kahneman, D., & Tversky, A. (1982). The simulation heuristic. In D. Kahneman, P. Slovic, and A. Tversky (Eds.), *Judgement under uncertainty: Heuristics and biases*. Cambridge University Press: Cambridge.
- Keil, F. C. (1992). *Concepts, kinds, and cognitive development*. Cambridge, MA: MIT Press.
- Kelemen, D. (1999). Function, goals and intention: Children's teleological reasoning about objects. *Trends in Cognitive Sciences*, 3(12), 461-468.
- Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction effects of direct instruction and discovery learning. *Psychological Science*, 15(10), 661-667.
- Koehler, D. J. (1991). Explanation, imagination, and confidence in judgment. *Psychological bulletin*, 110(3), 499.
- Koriat, A., Lichtenstein, S., & Fischhoff, B. (1980). Reasons for confidence. *Journal of Experimental Psychology: Human learning and memory*, 6(2), 107.
- Kuhn, D., & Katz, J. (2009). Are self-explanations always beneficial? *Journal of Experimental Child Psychology*, 103(3), 386-394.
- Kuhn, D., & Phelps, E. (1982). The development of problem-solving strategies. *Advances in Child Development and Behavior*, 17, 1-44.
- Kushnir, T., Gopnik, A., Schulz, L., & Danks, D. (2003, January). Inferring hidden causes. In *Proceedings of the Annual Meeting of the Cognitive Science Society* (Vol. 25, No. 25).
- Legare, C. H. (2012). Exploring explanation: Explaining inconsistent evidence informs exploratory, hypothesis-testing behavior in young children. *Child development*, 83(1), 173-185.
- Legare, C. H., & Lombrozo, T. (2014). Selective effects of explanation on learning during early childhood. *Journal of Experimental Child Psychology*, 126, 198-212.
- Lewis, D. (1986). *Counterfactuals*. Cambridge, MA: Harvard University Press.
- Lombrozo, T. (2006). The structure and function of explanations. *Trends in cognitive sciences*, 10(10), 464-470.
- Lombrozo, T. (2012). Explanation and abductive inference. *Oxford handbook of thinking and reasoning*, 260-276.
- Lombrozo, T., & Carey, S. (2006). Functional explanation and the function of explanation. *Cognition*, 99(2), 167-204.
- Lord, C. G., Lepper, M. R., & Preston, E. (1984). Considering the opposite: a corrective strategy for social judgment. *Journal of personality and social psychology*, 47(6), 1231.
- Lucas, C. G., Bridgers, S., Griffiths, T. L., & Gopnik, A. (2014). When children are better (or at least more open-minded) learners than adults: Developmental differences in learning the forms of causal relationships. *Cognition*, 131(2), 284-299.
- Mackie, J. L. (1974). Truth, probability, and paradox: A reply to James E. Tomberlin's review. *Philosophy and Phenomenological Research*, 34(4), 593-594.
- Markman, K. D., McMullen, M. N., & Elizaga, R. A. (2008). Counterfactual thinking, persistence, and performance: A test of the reflection and evaluation model. *Journal of Experimental Social Psychology*, 44(2), 421-428.

- McCormack, T., Butterfill, S., Hoerl, C., & Burns, P. (2009). Cue competition effects and young children's causal and counterfactual inferences. *Developmental psychology*, 45(6), 1563.
- McCormack, T., Simms, V., McGourty, J., & Beckers, T. (2013). Encouraging children to think counterfactually enhances blocking in a causal learning task. *Quarterly Journal of Experimental Psychology*, 66(10), 1910-1926.
- Mitchell, C. J., Lovibond, P. F., & Condoleon, M. (2005). Evidence for deductive reasoning in blocking of causal judgments. *Learning and Motivation*, 36(1), 77-87.
- Narvaez, D., Gleason, T., Mitchell, C., & Bentley, J. (1999). Moral theme comprehension in children. *Journal of Educational Psychology*, 91(3), 477.
- Nelson, K. (1973). Structure and strategy in learning to talk. *Monographs of the Society for Research in Child Development*, 38(No. 149).
- Nyhout, A., & Ganea, P. (under review). Mature counterfactual thinking in preschoolers.
- Nyhout, A., Iannuzziello, A., Walker, C.M., & Ganea, P.A. (in prep). Does exposure to "What if" scenarios during experimentation promote proper scientific reasoning in children?
- Pearl, J. (2000). Causal inference without counterfactuals: Comment. *Journal of the American Statistical Association*, 95(450), 428-431. doi: 10.2307/2669380
- Penner, D. E., & Klahr, D. (1996). The interaction of domain-specific knowledge and domain-general discovery strategies: A study with sinking objects. *Child Development*, 67(6), 2709-2727.
- Perner, J., & Rafetseder, E. (2011). Counterfactual and other forms of conditional reasoning: Children lost in the nearest possible world. In C. Hoerl, T. McCormack, & S. Beck (eds.), *Understanding Counterfactuals / Understanding Causation* (90-109). New York, NY: Oxford University Press.
- Rafetseder, E., & Perner, J. (2014). Counterfactual reasoning: sharpening conceptual distinctions in developmental studies. *Child development perspectives*, 8(1), 54-58. doi: 10.1111/cdep.12061
- Rafetseder, E., Schwitalla, M., & Perner, J. (2013). Counterfactual reasoning: From childhood to adulthood. *Journal of experimental child psychology*, 114(3), 389-404. doi: 10.1016/j.jecp.2012.10.010
- Rhodes, M., Leslie, S. J., Saunders, K., Dunham, Y., & Cimpian, A. (2018). How does social essentialism affect the development of inter-group relations? *Developmental science*, 21(1).
- Roese, N. J. (1997). Counterfactual thinking. *Psychological bulletin*, 121(1), 133.
- Roese, N. J., & Olson, J. M. (1997). Counterfactual thinking: The intersection of affect and function. In *Advances in experimental social psychology* (Vol. 29, pp. 1-59). Academic Press.
- Ross, L. D., Lepper, M. R., Strack, F., & Steinmetz, J. (1977). Social explanation and social expectation: Effects of real and hypothetical explanations on subjective likelihood. *Journal of Personality and Social Psychology*, 35(11), 817.
- Sanna, L. J., & Schwarz, N. (2003). Debiasing the hindsight bias: The role of accessibility Experiences and (mis) attributions. *Journal of experimental social psychology*, 39(3), 287-295.
- Sanna, L. J., Schwarz, N., & Stocker, S. L. (2002). When debiasing backfires: Accessible content and accessibility experiences in debiasing hindsight. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 28(3), 497.
- Schulz, L. E., & Gopnik, A. (2004). Causal learning across domains. *Developmental*

- psychology*, 40(2), 162.
- Schulz, L. E., Gopnik, A., & Glymour, C. (2007). Preschool children learn about causal structure from conditional interventions. *Developmental Science* 10(3), 322–332. doi: 10.1111/j.1467-7687.2007.00587.x
- Schwarz, N. (1998). Accessible content and accessibility experiences: The interplay of declarative and experiential information in judgment. *Personality and Social Psychology Review*, 2(2), 87-99.
- Schwarz, N., & Vaughn, L. A. (2002). The availability heuristic revisited: Ease of recall and content of recall as distinct sources of information. In T. Gilovich, D. Griffin, & D. Kahneman (Eds.), *Current perspectives on judgment under uncertainty* (2nd Ed). Cambridge, UK: Cambridge University Press.
- Seiver, E., Gopnik, A., & Goodman, N. D. (2013). Did she jump because she was the big sister or because the trampoline was safe? Causal inference and the development of social attribution. *Child development*, 84(2), 443-454.
- Siegler, R. S. (2002). Microgenetic studies of self-explanation. *Microdevelopment: Transition processes in development and learning*, 31-58.
- Simms, V., McCormack, T., & Beckers, T. (2012). Additivity pretraining and cue competition effects: Developmental evidence for a reasoning-based account of causal learning. *Journal of Experimental Psychology: Animal Behavior Processes*, 38(2), 180.
- Sloman, S. (2005). *Causal models: How people think about the world and its alternatives*. Oxford University Press.
- Sobel, D. M., Tenenbaum, J. B., & Gopnik, A. (2004). Children's causal inferences from indirect evidence: Backwards blocking and Bayesian reasoning in preschoolers. *Cognitive science*, 28(3), 303-333.
- Spellman, B. A., & Mandel, D. R. (1999). When possibility informs reality: Counterfactual thinking as a cue to causality. *Current Directions in Psychological Science*, 8(4), 120-123.
- Taylor, M. G. (1996). The development of children's beliefs about social and biological aspects of gender differences. *Child development*, 67(4), 1555-1571.
- Taylor, M. G., Rhodes, M., & Gelman, S. A. (2009). Boys will be boys; cows will be cows: Children's essentialist reasoning about gender categories and animal species. *Child development*, 80(2), 461-481.
- Tetlock, P., & Belkin, A. (1996). *Counterfactual Thought Experiments in World Politics*. Princeton, NJ: Princeton University Press.
- Tetlock, P. E., & Lebow, R. N. (2001). Poking counterfactual holes in covering laws: Cognitive styles and historical reasoning. *American Political Science Review*, 95(4), 829-843.
- Walker, C. M., Bonawitz, E., & Lombrozo, T. (2017). Effects of explaining on children's preference for simpler hypotheses. Invited paper for *Special Issue: The process of explanation* in *Psychonomic Bulletin & Review*. doi: 10.3758/s13423-016-1144-0
- Walker, C. M., Bridgers, S., & Gopnik, A. (2016). The early emergence and puzzling decline of relational reasoning: Effects of knowledge and search on inferring abstract concepts. *Cognition*, 156, 30-40.
- Walker, C.M., Buchsbaum, D., Banerjee, E., & Gopnik, A. (in prep) Imagining interventions: Complex causal reasoning in pretend play.

- Walker, C. M., & Gopnik, A. (2013a). Causality and imagination. *The Oxford handbook of the development of the imagination*, 342-358. doi: 10.1093/oxfordhb/9780195395761.013.0022
- Walker, C.M., & Gopnik, A. (2013b). Pretense and possibility: A theoretical proposal about the effects of pretend play on development: Comment on Lillard, Lerner, Hopkins, Dore, Smith, & Palmquist (2013). *Psychological Bulletin*, 139(1), 40-44.
- Walker, C. M. & Gopnik, A. (2014). Toddlers infer higher-order relational principles in causal learning. *Psychological Science*, 25(1): 161-169.
- Walker, C. M. & Gopnik, A. (2017). Discriminating relational and perceptual judgments: Evidence from human toddlers. *Cognition*, 166, 23-37.
- Walker, C. M. & Lombrozo, T. (2017). Explaining the moral story. Invited paper for *Special Issue: Moral Learning in Cognition*, 167, 266-281.
- Walker, C. M., Lombrozo, T., Legare, C., & Gopnik, A. (2014). Explanation prompts children to privilege inductively rich properties. *Cognition*, 133, 343-357. doi: 10.1016/j.cognition.2014.07.008
- Walker, C. M., Lombrozo, T., Williams, J. J., Rafferty, A. N., & Gopnik, A. (2016). Explaining constrains causal learning in childhood. *Child Development*, 88, 229-246. doi: 10.1111/cdev.12590
- Weisberg, D. S., & Gopnik, A. (2013). Pretense, counterfactuals, and Bayesian causal models: Why what is not real really matters. *Cognitive Science*, 37(7), 1368-1381.
- Wellman, H. M., & Gelman, S. A. (1992). Cognitive development: Foundational theories of core domains. *Annual review of psychology*, 43(1), 337-375. doi: 10.1146/annurev.ps.43.020192.002005
- Wellman, H. M., & Liu, D. (2007). Causal reasoning as informed by the early development of explanations. *Causal learning: Psychology, philosophy, and computation*, 261279.
- Wenzlhuemer, R. (2009). Counterfactual thinking as a scientific method. *Historical Social Research/Historische Sozialforschung*, 27-54.
- Wilkenfeld, D. A., & Lombrozo, T. (2015). Inference to the best explanation (IBE) versus explaining for the best inference (EBI). *Science & Education*, 24(9-10), 1059-1077.
- Williams, J. J. & Lombrozo, T. (2010). The role of explanation in discovery and generalization: evidence from category learning. *Cognitive Science*, 34, 776-806. doi: 10.1111/j.1551-6709.2010.01113.x
- Williams, J. J., & Lombrozo, T. (2013). Explanation and prior knowledge interact to guide learning. *Cognitive psychology*, 66(1), 55-84.
- Williams, J. J., Lombrozo, T., & Rehder, B. (2013). The hazards of explanation: Overgeneralization in the face of exceptions. *Journal of Experimental Psychology: General*, 142(4), 1006.
- Woodward, J. (2003). *Making things happen: A theory of causal explanation*. Oxford University Press: Oxford.
- Woodward, J. (2007). Interventionist theories of causation in psychological perspective. *Causal learning: Psychology, philosophy, and computation*, 19-36.
- Yu, Y., Bonawitz, E., & Shafto, P. (2017). Pedagogical Questions in Parent–Child Conversations. *Child Development* (online first). doi: 10.1111/cdev.12850
- Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. *Developmental Review*, 27(2), 172-223. doi: 10.1016/j.dr.2006.12.001

Zimmerman, C., & Glaser, R. (2001). Testing Positive versus Negative Claims: A Preliminary Investigation of the Role of Cover Story on the Assessment of Experimental Design Skills. *CSE Technical Report*.