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Finding the Cause: Verbal Framing Helps Children Extract Causal Evidence Embedded in a Complex Scene

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In making causal inferences, children must both identify a causal problem and selectively attend to meaningful evidence. Four experiments demonstrate that verbally framing an event ("Which animals make Lion laugh?") helps 4-year-olds extract evidence from a complex scene to make accurate causal inferences. Whereas framing was unnecessary when evidence was isolated, children required it to extract and reason about evidence embedded in a more complex scene. Subtler framing stating the causal problem, but not highlighting the relevant variables, was equally effective. Simply making the causal relationship more perceptually obvious did facilitate children's inferences, but not to the level of verbal framing. These results illustrate how children's causal reasoning relies on scaffolding from adults.

A universal challenge that young children face in the first years of life is to construct a functional and causal understanding of the world that enables them to make predictions, to construct accurate explanations, and to reason counterfactually about cause and effect. Although a growing body of literature suggests that preschoolers are capable of making a wide variety of causal inferences on the basis of probabilistic, statistical evidence (see Gopnik & Schulz, 2004), these empirical investigations have tended to focus on the capacities children demonstrate in ideal situations. But children rarely encounter causal evidence in such ideal situations, and the current research explores when and how children are able to apply their causal reasoning

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capacities in more complex, noisier contexts such as those often found in natural settings.

Broadly speaking, context can greatly affect children's ability to put their reasoning capacities to use. Consider a child who has a firm grasp of basic arithmetic. She can add and subtract two or three numbers and carry out basic multiplication and division problems; for example: $24 - 6 = 18$ and $18 \div 2 = 9$. Now imagine she is faced with a problem requiring identical arithmetic operations, but she must identify from a given context (e.g., "Jill has 24 marbles. She has 6 more than Bill had yesterday, before he gave half of his marbles to Joe. How many marbles does Bill have today?") Children, and even adults, have much greater difficulty with simple arithmetic when presented in notorious "word problems" such as these, despite the fact that they require the identical mathematical operations (cf., Mayer, Lewis, & Hegarty, 1992; Stern, 1993).

Although there are a number of reasons why children might find such problems difficult, this example illustrates that in investigating the development of any reasoning capacity, we must answer two sets of questions. First, what are the learning mechanisms that underlie a particular capacity, and how and when do they develop? Second, and equally important, when are children able to successfully make use of this reasoning capacity, and what factors are necessary to trigger or facilitate it in the relevant contexts? The first set of questions can be addressed by isolating that capacity and examining the development of the learning mechanisms that underlie it—for example, by stripping away context and testing children on purely arithmetic abilities. The second set of questions, however, must be addressed by systematically varying particular aspects of the context to investigate how they influence children's success at utilizing those abilities. In word problems, for example, the context and wording may fail to trigger the reasoning processes and computations necessary for the child to solve the problem.

Returning to the question of how children construct a functional, causal understanding of the world, one particularly fruitful approach has been to investigate preschoolers' ability to infer underlying causal structure on the basis of patterns of statistical evidence. In a seminal study, Gopnik, Sobel, Schulz, and Glymour (2001) investigated 2-, 3-, and 4-year-old children's ability to make judgments about which objects possessed a novel causal power on the basis of a statistical inference procedure known as "screening off" (Reichenbach, 1956),[1] in which children rule out spurious associations

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[1] It should be noted that Reichenbach's (1956) formulation of the "screening-off" problem is not by definition causal, but rather a calculation of conditional probabilities that may support causal judgments. However, for the purposes of this article, we will use the term "screening off" in the way that Gopnik et al. (2001) have operationalized it in their procedure—specifically the act of judging which of two possible causes that are associated with an event in fact *causes* it.

in favor of genuine causal relationships. On such tasks, the objective is to ascertain which of two (or more) possible events *causes* another event. To take Gopnik et al.'s example, imagine our friend notices that when she drinks wine (Event A) she has trouble sleeping (Event B). But she also realizes that she often drinks wine when she goes to a party (Event C). Thus, whereas both drinking wine and going to parties are *associated* with her insomnia, there are several possibilities as to what actually *causes* it. It is possible that drinking wine causes her insomnia and that going to parties is merely associated with drinking wine. Alternatively, it could be that the excitement of going to parties causes the insomnia, whereas drinking wine is merely associated with going to parties. If this was the case, drinking wine would be associated with insomnia but would not be its *cause*.

To test this, our friend would need to observe the conditional probabilities between the three events and judge which possible causal structure is the most likely, given the data. That is, she should manipulate the presence or absence of one event (for example, going to parties), while holding constant the presence of the second event (drinking wine), and vice versa, going to parties with or without drinking wine. If she finds that one event—say, going to parties—is associated with insomnia independently of whether or not she drinks wine, then we would say that drinking wine and insomnia are causally independent—or in Reichenbach's (1956) terms, going to parties "screens off" drinking wine. Gopnik et al. (2001) point out that although this sort of reasoning does not always lead to *accurate* causal judgments, adults do make use of such evidence in reasoning about cause and effect.

To test whether children can use similar "screening-off" logic to reason about causality, Gopnik et al. (2001) presented preschoolers with a "blicket machine" and told them that "blickets make the machine go." Children were then trained on judging which blocks were blickets on the basis of whether or not they activated the machine. In the test phase, children were presented with canonical "screening-off" evidence: Object A always turned the machine on, regardless of whether Object B was present; Object B turned the machine on 66% of the time, but only when Object A was present. Children correctly inferred that Object A, but not Object B, had the causal power and was a blicket on the basis of these patterns of conditional probability. Children were also able to figure out which object to *remove* to make the machine stop.

Sobel, Tenenbaum, and Gopnik (2004) extended these findings to show that 4-year-old children's judgments are not simply the result of calculations of associative strength, but rather represent true causal reasoning based on statistical patterns of covariation. Further, Schulz and Gopnik (2004) replicated Gopnik et al.'s (2001) results using both biological and psychological causal events, suggesting that 4-year-olds' ability to reason about statistical causal evidence may rely on a general learning mechanism that cuts across conceptual domains. They also demonstrated that children can reason about these patterns of evidence even when causality crosses domain boundaries, appears mechanistically implausible, and conflicts with an expected causal relationship. For example, children correctly used probabilistic evidence to infer that an unexpected physical action (flipping a switch), rather than an expected event (seeing drawings of silly faces), caused a psychological effect (a character giggling; Schulz & Gopnik, 2004, Experiments 4 and 5) and that intervening would stop the effect. Thus, although infants and young children have in some cases been shown to disregard covariation information when they have no knowledge of a plausible mechanism (see Madole & Cohen, 1995; Madole & Oakes, 1999), Schulz and Gopnik's (2004) work demonstrates that preschoolers will readily make causal inferences on the basis of probabilistic evidence even when a causal relationship has an opaque or even implausible causal mechanism.

Children this age also understand quite a bit about causal interventions and can craft appropriate interventions to cause or inhibit an effect (Gopnik et al., 2001; Schulz & Gopnik, 2004). Further, preschoolers can reason counterfactually about causal chains and whether the hypothetical presence or absence of a particular action would cause or fail to cause an event to take place (Harris, German, & Mills, 1996). They also can assess whether an intervention is informative, showing sensitivity to the ways in which interventions may be confounded by unseen factors (Kushnir & Gopnik, 2005). Additionally, they can correctly identify which of several possible causal systems best fits the given evidence and are capable of generating disambiguating evidence to figure out how a causal system works (Schulz, Gopnik, & Glymour, 2007). Finally, children are sensitive to the rationale an experimenter gives for an intervention, and this guides whether or not they make use of the evidence produced by that intervention (Sobel & Sommerville, 2009).

It is clear, then, that by preschool age, children have a set of statistical learning capacities that they are able to use to reason about causality—categorizing objects as causal or noncausal, making appropriate causal predictions, and planning and carrying out appropriate causal interventions. Indeed, there is some evidence that these learning mechanisms may already be in place by 24 months of age, if not earlier (Sobel & Kirkham, 2006, 2007). However, it is also important to ask how these learning capacities actually function given different environmental and contextual factors.

Indeed, it seems that children this age and older actually struggle in many situations that require the application of this type of causal reasoning to problem solving. In the most classic work in this vein, Inhelder and Piaget (1964) demonstrated that before early adolescence, children were poor at explicitly controlling and manipulating variables to infer their causal influence. More recent work, especially by Klahr (e.g., Chen & Klahr, 1999; Klahr & Nigam, 2004) and Kuhn (e.g., Kuhn, 1989; Kuhn, Black, Keselman, & Kaplan, 2000; Kuhn & Dean, 2004; Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Kuhn, Schauble, & Garcia-Mila, 1992) has supported the notion that school-aged children have difficulty reasoning about and manipulating variables on what they call "scientific reasoning" tasks. Further, this ability seems to take until adolescence or later to fully develop, despite the fact that such reasoning relies upon the same basic mechanisms as simpler causal inferences of which preschoolers are quite capable (see Kuhn & Dean, 2004; Kuhn, Katz, & Dean, 2004, for in-depth reviews). To take a concrete example from this literature, Kuhn et al. (2000) gave middle school students the task of planning to build cabins in a flood-prone area, a task that required them to reason about five different variables (e.g., water pollution and soil type) to ascertain which were causally relevant to flooding. Prior to an intervention teaching the students how to control variables, their performance was quite poor.

These two bodies of literature seem to paint two very different pictures of children's causal reasoning abilities. On one hand, the literature on preschoolers' causal reasoning (e.g., Gopnik et al., 2001; Schulz & Gopnik, 2004) demonstrates that even very young children have the capacity to make causal inferences based on patterns of probabilistic data. On the other hand, work with older children (e.g., Chen & Klahr, 1999; Klahr & Nigam, 2004; Kuhn, 1989) shows that some years later, they have difficulty applying analogous probabilistic inference capacities to scientific reasoning problems. As Kuhn and Dean (2004) point out, there are a number of factors, including the nature and complexity of the tasks, that may account for the discrepancy between early abilities to engage in probabilistic causal inference and later failures to apply similar cognitive abilities to scientific reasoning. There is a clear gap between these literatures, and our understanding of causal reasoning in preschoolers needs to be situated with respect to findings of difficulty with causal inferences in older children.

To do this, our first step was to identify factors present in work on preschoolers' causal reasoning that might have facilitated the activation and application of causal learning mechanisms to the problems at hand. Although our approach may be applied to many different paradigms, we have targeted the methodology used to investigate preschoolers' ability to "screen off" plausible causal variables on the basis of conditional probabilities. Specifically, we have focused on the work of Schulz and Gopnik (2004), as it has shown that children can reason in this way regardless of the domain or the mechanistic plausibility of the evidence.

As an illustrative example, take the work on children's causal inferences about what makes a character laugh (Schulz & Gopnik, 2004, Experiment 4). There are two factors in particular that may have facilitated children's ability to make accurate causal inferences based on the data. First, the causal event was completely isolated. Unlike many of the situations children routinely encounter, there were no other salient actions or events occurring in the experiment beyond the necessary actions taken to demonstrate the probabilistic evidence. Further, the only stimuli present were the possible causes, which had already been explicitly introduced to the children. This setup tremendously simplifies the problem of identifying which variables to include in a causal analysis.

Second, the causal problem was explicitly and verbally *framed* for the children. Prior to the test phase, they were given practice sorting items that might or might not make a character giggle, which may have prepared them to notice the causal relationship. Further, in the test phase, children were introduced to the puppet, were told that she was "pretty silly" and "giggles a lot," and were asked, "Can you help me figure out what makes Catherine giggle?" The experimenter thus provided explicit verbal framing, both pointing out a causal problem to be solved and specifying what the child should focus on. Although the precise instructions varied across different versions of this and other "screening-off" tasks, the causal relation was explicitly framed in one form or another in nearly every case.

As Markman and Jaswal (2003) have pointed out, when encountering causal events in more complex contexts, ones in which multiple and often overlapping actions and events occur, children face a difficult inductive problem. First, they must recognize that there is a causal relationship present that they can learn about. Second, they must determine which of many variables (e.g., objects, actions, and events) to attend to and include in a causal analysis. Isolating both the key events and causal variables as well as explicitly framing the causal problem, as was done in previous research, may have triggered children's causal analysis and drawn their attention to the relevant variables and relations they ought to focus on. This may have done a great deal of work for children in enabling them to make the correct causal inference. Indeed, work by Sobel and Sommerville (2009) has demonstrated that the rationale given for a causal intervention (e.g., as either for the purpose of figuring out how something works or simply because the experimenter likes it) affects whether children make use of the causal evidence generated by that intervention. Although Sobel and Sommerville's study did not directly target whether this type of framing affected whether children *noticed* the causal relation in the first place, or were *able* to reason about it, it does suggest that how adults frame the evidence they generate influences how children reason about it.

Having identified these potential triggers—isolating the causal event, framing the causal problem, and specifying the relevant variables—in the current research, we systematically manipulated each of these factors. In

Studies 1 and 2, we investigated the influence of both isolating the causal event and providing children with explicit verbal framing of the causal problem. We predicted that although verbal framing might not be necessary when a causal event was presented in isolation, it might be critical when children faced the problem of identifying the causal problem and relevant variables in a more complex scene. In Study 3, we tested whether a subtler verbal framing that called attention to the causal problem, but did not specify the variables relevant to the causal analysis, would be sufficient to facilitate children's causal reasoning. Finally, in Study 4, we asked whether simply making the causal relationship more salient would accomplish the same feat as providing verbal framing. This systematic approach allowed us to gain traction on the problem of how and when each of these factors might impact children's ability to successfully make causal inferences on the basis of identical probabilistic data.

STUDY 1

In Studies 2 through 4, we will explore what factors influence when and how children make use of causal evidence in more complex contexts. In Study 1, however, we begin with the simplest case. In previous research that demonstrated children's ability to "screen off" spurious associations and infer which variables have a true causal relationship (e.g., Schulz & Gopnik, 2004), the causal event was both isolated and verbally framed for the child. To begin teasing apart the relative roles of these two factors, here we also presented children with causal evidence in isolation, with no additional events or actions taking place, but varied whether the causal problem was verbally framed.

Although verbal framing may be necessary when children face the added problems of figuring out what to attend to and what evidence to extract from a more complex scene, they might not need such additional guidance to make a causal inference when the relevant evidence is presented in isolation. If so, then we would predict a lack of condition differences in Study 1. This result might be particularly informative when compared with children's performance in Studies 2 through 4, where they encounter evidence in less ideal situations.

Method

Participants

The participants were thirty-two 4-year-old children ($M = 4;4$; range = 4;1–4;10) recruited and tested at a university preschool. The children were predominately Caucasian and middle to upper class, but a diversity of social and ethnic backgrounds was represented in the sample. Half of the children were male and half were female. Children were randomly assigned to either a Framing condition or a No Framing condition, with the constraint that they be equated for gender and age across conditions. For the purpose of clarity across the studies reported in this article, we will refer to these two conditions as Isolated-Framing and Isolated-No Framing. Children received no incentives or rewards for participating in these studies.

Procedure

We presented children with probabilistic evidence for a causal relation that had been used in prior studies of causal learning (making a character laugh; Schulz & Gopnik, 2004), about which they would not have strong prior expectations in terms of what causes would be plausible or what particular causal mechanism might be functioning. This allowed us to test the roles of isolating and verbally framing the causal event in a case where prior expectations would not necessarily dictate the focus of children's attention or the inferences they make.

Children were tested in a small room in their school. When they entered the room, they were seated at a table across from the experimenter. The table was set up with six target items: three small, green, plastic dinosaur toys and three small, brown, plastic horses. They were first introduced to a lion puppet. In the Isolated-Framing condition, children were then given explicit framing of the problem: "Some animals make Lion laugh. Will you help me figure out which animals make Lion laugh?" In the Isolated-No Framing condition, the experimenter did not provide any framing and proceeded directly to the presentation phase of the experiment.

Presentation Phase

The presentation phase was identical in both conditions. For the purpose of clarity, we will refer to the causal animal (either dinosaur or horse, counterbalanced across subjects) as A and the noncausal animal as B. We will refer to the two animals together as AB. Following prior research (Schulz & Gopnik, 2004), the evidence was presented in one of the following two orders: A, B, AB, AB, or B, A, AB, AB.

On causal trials (A or AB), Lion approached the animal(s), picked it (them) up, and walked halfway across the table. He stopped, laughed, and then continued on and put it (them) in a small box at the end of the table.

On the noncausal trial (B), Lion approached the animal, picked it up, and walked halfway across the table. He stopped, said, "Hmmm," then continued on and put it in the box at the end of the table.

Test Phase

Children received four test questions. Two of these questions had previously been used in similar studies (see Schulz & Gopnik, 2004)—specifically a canonical forced-choice question that asked which of the two animals had the causal power to make the puppet laugh and an intervention question that asked children to use their causal inference to actually make the puppet laugh. We asked the intervention question because, as Schulz and Gopnik (2004) point out, it would be possible for children to respond correctly to the prediction question on the basis of a belief that both animals have a causal power but that one is simply a better answer. Allowing children to generate their own action to bring about the effect yields a more accurate picture of children's causal inference. These questions were included to make comparisons to previous research as straightforward as possible.

We also asked children two additional test questions to probe more deeply into their causal representations. The first was a purely open-ended question to see if they could describe the causal structure on their own. This was done because even simply asking a forced-choice question (e.g., "Which animal makes Lion laugh?") retroactively frames the event for the child by narrowing the possible answers, and we wanted to get a less constrained measure of children's inferences. Finally, we asked an extension question to see whether children had truly "screened off," understanding that each of the individual animals of a particular kind had the causal power and that none of the other kind of animal did.

In addition to giving us data on four different aspects of children's causal representations, these questions allowed us to create a composite score for each child that may provide a more sensitive measure of their causal inferences in general. The four test questions are described in more detail below and were always presented in the same order to avoid biasing later questions.

Open-ended question. After all the items had been put away, the experimenter removed the lion puppet from view and simply asked children, "What makes Lion laugh?"

Forced-choice question. Children were presented with the two animals and asked, "Can you give me the animal that makes Lion laugh?" This question was the canonical forced-choice question used in much of the prior work on children's causal learning.

Extension question. Children were presented with the four combinations of animals in one of the following two orders: A, AB, B, AB, or B, AB, A, AB. They received the first order if they saw B first in the presentation phase, and they received the second order if they saw A first in the presentation phase. The experimenter then asked the child, "Can you show me all the ones that make Lion laugh?" This question was included to further test the specificity of children's causal understanding. If children are truly "screening off" and not simply responding to the single-cause trials where they see one animal in isolation, if presented with a pair of animals, they should single out the correct animal in each pair as the cause.

Intervention question. Finally, the children were presented with the two animals, as well as the Lion puppet, and were asked, "Can you make Lion laugh?" If children did not answer at first, they were prompted, "Can you give Lion an animal to make him laugh?" Regardless of children's responses, the experimenter made the puppet laugh to give them a positive outcome at the end of the study.

Results

Coding and Data Analysis

Children were given a 1 for each question that they responded to correctly and a 0 for each question they responded to incorrectly. A more detailed description of the coding and data analysis procedures follows.

For the open-ended question, children were only given credit for a correct response if they produced the name of the correct animal, either in singular form (e.g., "the horse"), plural form (e.g., "the horses"), or generic form (e.g., "horses"). All other responses, including producing the name of the wrong animal, as well as responses that lacked specificity (e.g., "the animals") were coded as incorrect. These data were compared only across conditions, as a general expected level of chance responding cannot be determined.

For the forced-choice question, children were given a 1 if they chose the correct animal and a 0 for all other responses, including choosing both animals. These data were compared both across conditions and against a chance level of 50%.

For the extension question, we were particularly conservative about what counted as a correct response. Children were given a score of 1 only if they singled out each of the correct animals and were given a 0 for all other responses, including giving only one or two of the correct animals and giving the correct single animal plus both pairs of animals. Because there were six individual animals that children could choose from, in any of up to 64 possible combinations, calculating a chance level of responding is not particularly helpful, and thus, data were only compared across conditions.

For the intervention question, as for the forced-choice question, children were only given a 1 if they indicated only the correct animal. Although a "both" response might be technically a correct way to bring about the effect, it is not informative as to whether children have successfully inferred the causal structure and thus was given a 0. These data were compared both across conditions as well as against a chance level of 50%.

The data from each question were also summed to produce a composite score (0 to 4) for each child. Although this score cannot be compared to chance, it gives us a general measure of how children's ability to infer the causal relationship may differ across conditions. It should be noted that children's responses on each of the four questions were highly correlated (all rs $> .4$, ps $< .03$), indicating that the four questions assessed the same general causal inference.

Question-by-Question Analysis

There were no differences between conditions on any of the test questions (see Figure 1). A further breakdown by question is included below.

Open-ended question. When asked simply, "What makes Lion laugh?" 7 out of 16 children in the Isolated-No Framing condition and 8 out of 16 in the Isolated-Framing condition responded correctly. This difference was not significant, $\chi^2(1) = 0.13$, $p = .72$.

Forced-choice question. When asked to indicate which of the two animals made Lion laugh, 14 out of 16 children in the Isolated-No Framing

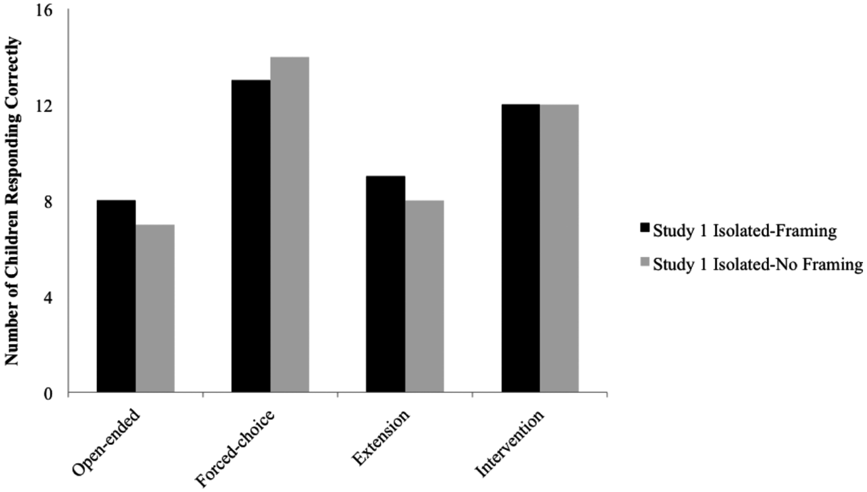

FIGURE 1 Number of children in Study 1 responding correctly across questions.

condition responded correctly, which was better than chance, $\chi^2(1) = 9.00$, $p < .01$. In the Isolated-Framing condition, 13 out of 16 children responded correctly. Replicating previous studies (Schulz & Gopnik, 2004), children in the Isolated-Framing condition were above chance, $\chi^2(1) = 6.25$, $p < .02$. The difference between conditions was not significant, $\chi^2(1) = 0.24$, $p = .63$.

Extension question. When asked to indicate *all* of the animals that made Lion laugh, 8 out of 16 children in the Isolated-No Framing condition and 9 out of 16 in the Isolated-Framing condition responded correctly (by singling out all three target animals). This difference was not significant, $\chi^2(1) = 0.13$, $p = .72$.

Intervention question. When asked if they could make Lion laugh, 12 out of 16 children in each condition responded correctly. This was better than chance, $\chi^2(1) = 4.00$, $p < .05$.

Composite Score

Children in the Isolated-No Framing condition had a mean composite score of 2.56 out of 4 ($SD = 1.03$), whereas children in the Isolated-Framing condition had a mean composite score of 2.63 out of 4 ($SD = 1.59$). Children were equally successful at making accurate causal inferences in both conditions, $t(30) = 0.13$, $p = .90$. Thus, when evidence was presented in isolation, there was no effect of providing verbal framing on children's ability to correctly infer which animal made the lion puppet laugh.

Discussion

When the causal event was presented in isolation, children were readily able to make a causal inference on the basis of probabilistic evidence, even given a somewhat more subtle causal relationship and one about which they may have had few expectations. This is particularly evident on the forced-choice and intervention questions, in which children's performance was clearly above chance, closely mirroring the results found by Schulz and Gopnik (2004) using similar methods. Although performance on the open-ended and extension questions may seem relatively low, these are questions that have many more possible answers and that may be more difficult than questions that constrain children's responses. And although we have no baseline from prior research for which to compare children's performance, the lack of a condition difference on these questions indicates that children were equally good at answering them whether or not the causal event had been verbally framed.

Thus, when evidence was presented in isolation, children were equally able to make the correct causal inference regardless of whether they heard explicit framing of the causal problem prior to seeing the evidence. In this study, children needed only to attend to the conditional probabilities of the events to make the correct causal inference. But in many of the potential learning opportunities that children encounter in their everyday lives, they face the added task of *extracting* this causal evidence from a more complex scene with a number of extraneous actions and events occurring at once. Having an adult verbally frame a causal problem may be particularly helpful in addressing this issue, as it may serve to tell the child what to look for in a noisy scene. In Study 2, children are presented with identical statistical evidence but in a situation in which they must extract this evidence from a more complex scene. Are children able to extract that evidence on their own, or do they require explicit framing of the event to isolate the relevant variables and make the appropriate computation to support the causal inference? Study 2 addresses this question.

STUDY 2

As in Study 1, children were presented with probabilistic causal evidence consistent with prior "screening-off" tasks. However, in Study 2, the evidence was embedded in a more complex scene. Children either received verbal framing before the task, which highlighted both the causal relationship and the question to be answered, or received no such framing.

Method

Participants

The participants were an additional thirty-two 4-year-old children ($M = 4;5$; range $= 4;0–4;10$) recruited and tested at a university preschool, with comparable social and ethnic backgrounds to those in Study 1. Half of the children were male and half were female. Children were randomly assigned to either a Framing condition or a No Framing condition, with the constraint that they be equated for gender and age across conditions. For the purpose of clarity we will refer to these conditions as Embedded-Framing and Embedded-No Framing.

Procedure

Children were tested in a small room in their school. When they entered the room, they were seated at a table across from the experimenter. The table was set up with a number of items. As in Study 1, the target items were three small, green, plastic dinosaur toys and three small, brown, plastic horse toys. The distractor items were a pair of toy shoes, a toy shirt, a toy hat, and two small, colored blocks. There was also a small toy box at one end of the table.

In this case, the evidence was embedded in an overarching event. Children were introduced to a lion puppet and were told, "This is Lion's room. Lion's room is very messy, isn't it? Lion is going to clean up all of his things and put them away." In the Embedded-Framing condition, children were then given explicit framing of the problem: "Some animals make Lion laugh. Will you help me figure out which animals make Lion laugh?" In the Embedded-No Framing condition, the experimenter did not provide any framing and proceeded directly to the presentation phase of the experiment.

Presentation Phase

The presentation phase was identical in both conditions. The experimenter moved the Lion toward the book and said, "Let's put this away." The lion picked up the book, walked across the table, and put it away in the toy box. Children received four familiarization trials: two books and two toy cars. This was done to familiarize children with the task of Lion cleaning up his room.

The presentation of the relevant evidence was also identical for each of the two conditions. As in Study 1, we will refer to the causal animal (either dinosaur or horse, counterbalanced across subjects) as A and the noncausal animal as B. We will refer to the two animals together as AB. The evidence was presented in one of the following two orders: A, B, AB, AB, or B, A, AB, AB.

On causal trials (A or AB), Lion approached the animal(s) and said, "Let's put this (these) away." Then, as in Study 1, he picked it (them) up and walked halfway to the toy box. He then stopped, laughed, and then continued on and put it (them) in the toy box.

On the noncausal trial (B), Lion approached the animal and said, "Let's put this away." Then, as in Study 1, he picked it up and walked halfway to the toy box. He then stopped, said, "Hmmm," then continued on and put it in the toy box.

On distractor trials (shoes, shirt, hat, blocks), which occurred between each of the animal trials, Lion approached the item(s) and said, "Let's put this (these) away." Then, as in Study 1, he picked it (them) up and put it (them) in the toy box.

Test Phase

The test phase was identical to that used in Study 1. Children received the same four test questions.

Results

The coding scheme and data analysis in Study 2 and all subsequent studies were identical to those used in Study 1. As in Study 1, for each child, we calculated a composite score (0 to 4) across the test questions. Children's responses to each of the test questions were highly correlated, indicating that they assessed the same general inference.

Question-by-Question Analysis

In marked contrast to the results of Study 1, in which children saw evidence in isolation and were equally able to make the inference whether or not the causal problem was framed for them, children in Study 2 responded significantly better on all questions in the Embedded-Framing condition than in the Embedded-No Framing condition (see Figure 2). A further breakdown by question is included below.

Open-ended question. When asked simply, "What makes Lion laugh?" only 1 out of 16 children in the Embedded-No Framing condition responded correctly compared with 9 out of 16 in the Embedded-Framing condition. The difference between conditions was significant, $\chi^2(1) = 9.31$, $p = .002$.

Forced-choice question. When asked to indicate which of the two animals made Lion laugh, only 4 out of 16 children in the Embedded-No

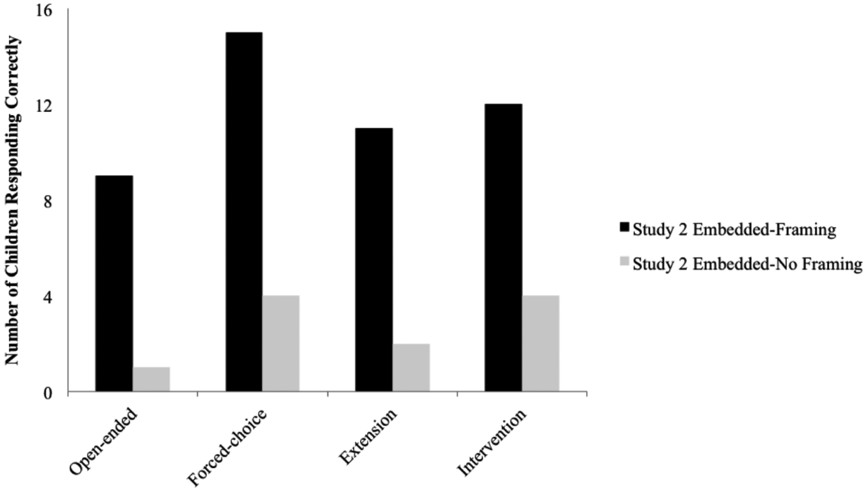

FIGURE 2 Number of children in Study 2 responding correctly across questions.

Framing condition chose the correct animal. Unlike previous research in which framing was present and the event was presented in isolation (Gopnik et al., 2001; Schulz & Gopnik, 2004), children's performance in the Embedded-No Framing condition of the current study was significantly below chance, $\chi^2(1) = 4.00$, $p < .05$. By contrast, 15 out of 16 in the Embedded-Framing condition responded correctly, which was significantly above chance, $\chi^2(1) = 12.3$, $p < .001$. Further, the difference between conditions was also significant, $\chi^2(1) = 15.6$, $p < .001$, with children performing much better when given framing of the causal question and relevant variables.

Extension question. When asked to indicate *all* the ones that made Lion laugh, only 2 out of 16 children in the Embedded-No Framing condition consistently chose correctly, compared with 11 out of 16 in the Embedded-Framing condition. The difference between conditions was significant, $\chi^2(1) = 10.4$, $p < .001$.

Intervention question. When asked if they could make Lion laugh, only 4 out of 16 children in the Embedded-No Framing condition chose the correct animal, which was significantly below chance, $\chi^2(1) = 4.00$, $p < .05$. In contrast, 12 out of 16 children in the Framing condition answered correctly, which was significantly above chance, $\chi^2(1) = 4.00$, $p < .05$. The difference between conditions was significant, $\chi^2(1) = 8.00$, $p = .005$.

Composite Score

Children in the Embedded-No Framing condition had a mean composite score of 0.56 out of 4 ($SD = 1.09$), indicating a striking inability to make the correct causal inference. In marked contrast, children in the Embedded-Framing condition had a mean composite score of 2.94 out of 4 ($SD = 1.24$), indicating they were relatively successful at using the statistical evidence to make the correct causal inference. This difference was significant, $t(30) = 5.755$, $p < .001$. Thus, removing factors that help to isolate and emphasize the causal problem and relevant variables eliminated children's well-documented ability to use the available statistical evidence to support a causal inference.

Discussion

The aim of Study 2 was to further tease apart the relative roles of isolation and verbal framing in children's ability to make causal inferences on the basis of probabilistic evidence. Although, in Study 1, children could use isolated evidence to support causal inferences without the problem being verbally framed, in Study 2, the verbal framing was critical in helping children identify and extract causal evidence from a more complex scene—even one that fell short of the complexity of real-world situations children are likely to encounter on a daily basis.

Although this demonstrates the role that verbal framing may play in facilitating children's ability to extract and analyze causal evidence from a more complex scene, the precise mechanism underlying this effect is as yet unknown. An intriguing possibility may be that children in Study 2 simply did not know where to direct their attention and that hearing the verbal frame helped them do so early enough to pick up on all of the relevant evidence. Of all the actions the character engaged in, only the four animal trials generated relevant evidence for the causal analysis. Thus, the verbal frame may have literally directed children to pay attention to the animals, therefore highlighting the instances that provided evidence necessary to assess the causal structure.

Indeed, the framing in the present experiment, as in prior research, had two components to it. First, it may have helped trigger a causal analysis by presenting children with a causal question: "What makes Lion laugh?" Second, it may have directed their attention to the instances that would generate relevant evidence (and helped them to ignore the irrelevant actions) by specifying the causal variables involved: "Some *animals* make Lion laugh." In Study 3, we address whether explicitly directing children's attention to the relevant variables is necessary to facilitate children's ability to extract causal evidence from a more complex scene, or whether a "partial" framing, which simply presents a causal question without giving children information about where to direct their attention, is sufficient.

STUDY 3

In Study 3, children were given partial framing that highlighted the causal problem but that did not direct children's attention to the relevant variables. They then saw the same presentation of evidence embedded in a naturalistic context and answered the same test questions as in Study 2.

Methods

Participants

Participants were an additional sixteen 4-year-old children ($M = 4;6$; range = 4;0–4;10) recruited from a university preschool. Half the children were male and half were female.

Procedure

The procedure was identical to the Embedded-Framing condition of Study 2 in which the causal problem was embedded in a scene where a character was cleaning up his room. The only difference in Study 3 (Embedded-Partial Framing) was the wording of the framing given to the children. In Study 2, children in the Framing condition were told, "Some *animals* make Lion laugh. Will you help me figure out *which animals* make Lion laugh?" In Study 3 (Embedded-Partial Framing), by contrast, after being told that Lion was going to clean up his room, children were told, "Some *things* make Lion laugh. Will you help me figure out *what* makes Lion laugh?" This "partial" framing served to tell children what the causal problem to be solved was, without specifying which objects the child should pay attention to.

Results

Question-by-Question Analysis

The question-by-question analysis yielded fairly comparable results to Study 2, with partial framing being nearly as effective as the full framing in the Embedded-Framing condition of Study 2 (see Figure 3). In the analyses that follow, the results of Study 3 will be referred to as the Embedded-Partial Framing version.

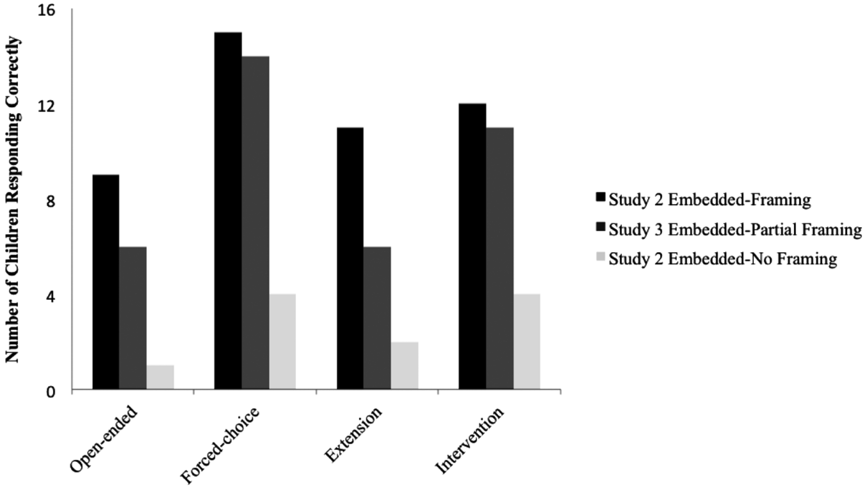

FIGURE 3 Number of children in Studies 2 and 3 responding correctly across questions.

Open-ended question. When asked simply, "What makes Lion laugh?" 6 out of 16 children in the Embedded-Partial Framing version responded correctly on the open-ended question. This was not significantly different from performance in the Embedded-Framing condition of Study 2 in which 9 out of 16 responded correctly, $\chi^2(1) = 1.13$, $p = .228$. It was, however, significantly better than performance in the Embedded-No Framing condition of Study 2, in which only 1 out of 16 responded correctly, $\chi^2(1) = 4.58$, $p = .033$.

Forced-choice question. When asked to indicate which animal made Lion laugh, 14 out of 16 children in the Embedded-Partial Framing version responded correctly. This was nearly identical to children's performance in the Embedded-Framing condition of Study 2, in which 15 responded correctly, $\chi^2(1) = 0.37$, $p = .544$. It was also significantly better than children's performance in the Embedded-No Framing condition, in which only 4 out of 16 responded correctly, $\chi^2(1) = 12.7$, $p < .001$. As in the Embedded-Full Framing condition of Study 2, children's performance in the Embedded-Partial Framing version was above chance, $\chi^2(1) = 9.00$, $p = .003$.

Extension question. When asked to indicate *all* the ones that made Lion laugh, 6 of out 16 children in the Embedded-Partial Framing version responded correctly on the extension question. This was marginally worse than performance in the Embedded-Framing condition of Study 2, in which 11 out of 16 responded correctly, $\chi^2(1) = 3.14$, $p = .077$, and was also not better than chance, $\chi^2(1) = 1.33$, $p = .248$. This suggests that the full framing given in the Embedded-Framing condition of Study 2 may have better facilitated the "screening-off" process. Children's performance in the Embedded-Partial Framing version was also marginally better than performance in the Embedded-No Framing condition of Study 2, in which 2 out of 16 responded correctly, $\chi^2(1) = 2.67$, $p = .102$.

Intervention question. When asked if they could make Lion laugh, 11 out of 16 children in the Embedded-Partial Framing version responded correctly. This was nearly identical to the Embedded-Framing condition of Study 2, in which 12 out of 16 responded correctly, $\chi^2(1) = 0.16$, $p = .694$, although children's performance in the Embedded-Partial Framing version was not different from chance, $\chi^2(1) = 2.25$, $p = .134$. Children's performance in the Embedded-Partial Framing version was also significantly better than the Embedded-No Framing condition of Study 2, in which only 4 out of 16 responded correctly, $\chi^2(1) = 6.15$, $p = .013$.

Composite Score

As in Studies 1 and 2, children's responses to the four test questions were highly correlated, and a composite score was calculated for each child by adding the scores from each individual test question (0 if incorrect, 1 if correct). In Study 3 (Embedded-Partial Framing), when children received only a partial version of the framing, which conveyed the causal question ("What makes Lion laugh?"), but no information about which variables on which to base an inference, they had a mean composite score of 2.31 out of 4 ($SD = 1.40$). This was significantly better than performance in the Embedded-No Framing condition of Study 2, in which children had a mean composite score of only 0.56, $t(30) = 4.128$, $p < .001$. Moreover, it was just as high as performance in the Embedded-Framing condition of Study 2, in which children had a mean composite score of 2.94, $t(30) = 1.338$, $p = .191$. Thus, even a partial framing of the causal question was equally as effective as full framing in enabling children to use the evidence to make a novel causal inference.

Discussion

Highlighting the causal problem, without drawing children's attention to specific variables in the environment that should be included in an analysis, helped children extract causal evidence embedded in a naturalistic context. Simply guiding a child toward thinking about a particular causal problem may sometimes be sufficient to help them know what to look for in a complex scene and may enable them to extract the relevant evidence to support a causal inference. It may not be necessary to literally guide children's attention to particular aspects of an event. Something as simple as asking a causal question may be a powerful tool in scaffolding children's causal learning and helping them take advantage of a learning opportunity that they might not otherwise notice.

This is not to say, of course, that there are not situations in which more extensive framing that explicitly directs children's attention is necessary. Faced with more subtle causal events, or evidence embedded in an even more complex scene, children may well require adult input that calls attention both to the causal problem and the relevant variables.

STUDY 4

In Studies 1 through 3, we investigated the relationship between the complexity of the scene in which evidence is embedded and the importance of adult framing of causal problems. When probabilistic evidence was embedded in a complex scene, children were only able to use the statistical evidence to infer which of the animals produce the causal effect when given explicit framing of the causal problem. We turn now to consider the role that the saliency of the event plays in children's ability to initiate a causal analysis. Recall that the event that children witnessed in the previous studies was somewhat subtle, as the puppet laughed *after* he had picked up the animals and while he was carrying them across the table. That is not to say that the event was too subtle for children to pick up on. Children in Study 1, who saw the event in isolation, were perfectly able to carry out the appropriate causal analysis without framing; and even a partial framing (as in Study 3) was sufficient for children to pick up on the evidence. But framing may be particularly vital when a causal relation is relatively subtle. If this is the case, then when children see identical evidence, in an identical context, but the causal relation is made more perceptually obvious, they may be better able to make the correct causal inference without verbal framing by an adult.

Method

Participants

Participants were an additional sixteen 4-year-old children ($M = 4;5$; range = 4;0–4;10) recruited from a university preschool. Half the children were male and half were female.

Procedure

The initial portion of the procedure, in which children were familiarized with the process of Lion cleaning up his room, was identical to that from Study 2. Children were tested only in a No Framing condition and so were simply introduced to the Lion puppet and told, "This is Lion's room. Lion's room is very messy, isn't it? Lion is going to clean up all of his things and put them away."

The statistical evidence children saw was identical to that in Study 2. However, recall that in Study 2, Lion picked up the animals, walked halfway to the toy box, stopped, and then either laughed or said, "Hmmm," before continuing to the toy box. In the present experiment, the causal relation was made more salient. In this version of the task, Lion deliberately looked at the animals and either laughed or said, "Hmmm," before picking them up.

On causal trials, Lion approached the animal(s) and said, "Let's put this (these) away." He then deliberately looked at the animal(s) and laughed. Then, he picked it (them) up and went to put it (them) away in the toy box.

On the noncausal trial, Lion approached the animal and said, "Let's put this away." He then deliberately looked at the animal and said, "Hmmm." Then, he picked it up and went to put it away in the toy box.

On distractor trials (shoes, shirt, hat, blocks), Lion approached the item(s) and said, "Let's put this (these) away." He then picked it (them) up and put it (them) in the toy box.

Results

We compared Study 4, in which children saw the more salient causal relation (Lion stopped, looked at the animals, and laughed before picking them up) and received no framing, and Study 2, in which children saw the more subtle causal relation (Lion stopped halfway to the toy box and laughed) and either received framing or not. For the purposes of clarity, in the discussion below, we will refer to Study 4 as the Embedded-More Salient-No Framing version.

Question-by-Question Analysis

Whereas the mean composite score in Study 4 (Embedded-More Salient-No Framing) was significantly different from both conditions of Study 2, the extent to which children performed differently on particular questions varied greatly (see Figure 4). For each question, we compare the Embedded-More Salient-No Framing condition from the current study with the Embedded-Framing and Embedded-No Framing conditions of Study 2.

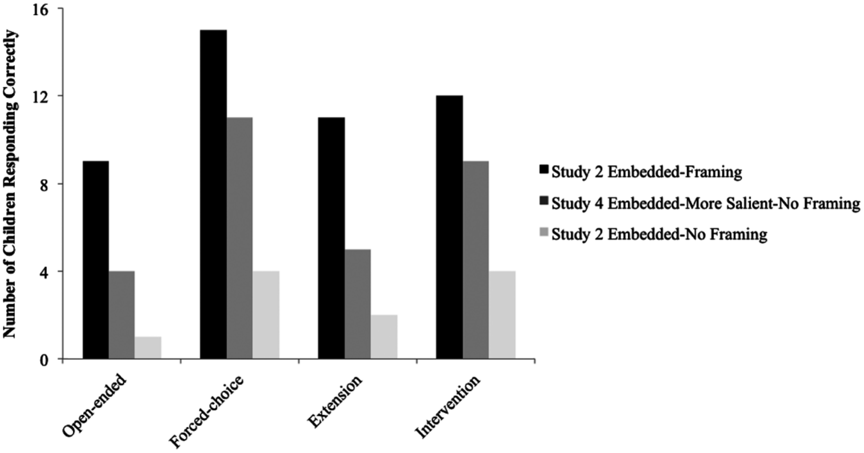

FIGURE 4 Number of children in Studies 2 and 4 responding correctly across questions.

Open-ended question. When children were shown a more salient causal event in Study 4 (Embedded-More Salient-No Framing) and asked simply, "What makes Lion laugh?" 4 out of 16 children responded correctly. This was not significantly different from the performance in the Embedded-No Framing condition of Study 2 where children saw a more subtle causal relation and in which only 1 out of 16 responded correctly, $\chi^2(1) = 2.13$, $p = .144$. This was also marginally worse than the performance of children in the Embedded-Framing condition of Study 2, in which 9 out of 16 responded correctly, $\chi^2(1) = 3.24$, $p = .072$.

Forced-choice question. When asked to indicate which animal made Lion laugh, 11 out of 16 children responded correctly. This was significantly better than children's performance in the Embedded-No Framing condition of Study 2, in which only 4 out of 16 responded correctly, $\chi^2(1) = 6.15$, $p = .013$, but was not significantly different from chance, $\chi^2(1) = 2.25$, $p = .134$. It was also marginally worse than children's performance in the Embedded-Framing condition of Study 2, in which 15 out of 16 responded correctly, $\chi^2(1) = 3.28$, $p = .070$.

Extension question. When asked to indicate *all* the ones that made Lion laugh, 5 out of 16 children responded correctly on the extension question. This was not significantly different from children's performance in the Embedded-No Framing condition of Study 2, in which 2 out of 16 responded correctly, $\chi^2(1) = 1.64$, $p = .20$. Furthermore, it was significantly worse than children's performance in the Embedded-Framing condition of Study 2, in which 11 out of 16 responded correctly, $\chi^2(1) = 4.50$ $p = .034$.

Intervention question. When asked if they could make Lion laugh, 9 out of 16 children indicated the correct animal. This was marginally better than children's performance in the Embedded-No Framing condition of Study 2, in which only 4 out of 16 responded correctly, $\chi^2(1) = 3.24$, $p = .072$, but was not significantly different from chance, $\chi^2(1) = 0.250$, $p = .617$. It was not, however, significantly worse than children's performance in the Embedded-Framing condition of Study 2, in which 12 out of 16 responded correctly, $\chi^2(1) = 1.25$, $p = .264$.

Composite Score

As in the previous studies, children's responses across the four test questions were highly correlated, and a composite score was calculated for each child by adding the scores from each individual test question (0 if incorrect, 1 if correct). In Study 4 (Embedded-More Salient-No Framing), children had a mean composite score of 1.81 out of 4 ($SD = 1.60$), which was significantly lower than the mean composite score of 2.94 in the Embedded-Framing condition of Study 2, $t(30) = 2.225$, $p = .034$, indicating that children did not perform as well without framing, despite the increased clarity of the causal relation. On the other hand, this was significantly higher than the mean composite score of 0.56 in the Embedded-No Framing condition of Study 2, $t(30) = 2.579$, $p = .015$), suggesting that, even without framing, children performed somewhat better when the causal relation was made more salient.

Discussion

Making the causal relation more salient slightly improved children's performance relative to the Embedded-No Framing version of Study 2, in which they saw a subtler causal event. However, this appears to be true only on the two questions in which children were given a forced choice between two animals (the forced-choice and intervention questions), and on neither question did their performance rise above the chance level as it had when children were given framing in Study 2. Making the causal relation somewhat more salient only minimally helped children extract the relevant evidence from the naturalistic context. Taken together with the results of the previous studies, it appears that isolation and verbal framing play particularly important roles in scaffolding children's causal inferences, potentially more so than the exact manner in which the causal evidence is produced.

GENERAL DISCUSSION

Children have well-documented abilities to reason about cause and effect, to learn novel causal structures, to make a variety of causal inferences on the basis of probabilistic evidence, and to incorporate those inferences into a theoretical framework (Gopnik & Schulz, 2004; Gopnik & Sobel, 2000; Gopnik et al., 2001; Schulz & Gopnik, 2004). And yet in many cases, children, and even adults, have been shown to have difficulty applying similar reasoning abilities to a number of different tasks (Chen & Klahr, 1999; Klahr & Nigam, 2004; Kuhn, 1989; Kuhn & Dean, 2004; Kuhn et al., 1992, 1995, 2000). The current work demonstrates that preschoolers are not always able to make accurate causal inferences when faced with the added problem of identifying and extracting evidence from situations more like those they often encounter in their daily lives. In such cases, when evidence is embedded in a more complex scene with many actions and events, verbally framing the causal problem—even simply asking a causal question—enables children to extract that evidence and use it in a causal analysis.

What mechanisms might underlie the effects seen in the present research? As discussed previously, one possibility is that verbally framing the causal problem directed children's attention in a way that facilitated their ability to capitalize on the probabilistic evidence available to them. However, it was not necessary to literally direct children's attention to potential causes to facilitate their causal reasoning. Simply highlighting the fact that there was a particular causal problem to be solved was sufficient. This may have informed children about what general kind of event to watch for (i.e., the puppet laughing) without specifying where to look or what variables to include in a causal analysis.

Another possibility, and one that does not preclude the first, is that verbally framing the causal problem acted as a type of scaffolding that enabled children to recognize and select evidence from a more complex scene—something that might have been just beyond their grasp otherwise. This explanation builds on Vygotsky's (1978) notion of the Zone of Proximal Development—the range of problems that lie within a child's cognitive abilities but that they can only solve with at least some scaffolding from an adult. Indeed, many studies demonstrate the power of various forms of scaffolding in facilitating children's cognitive abilities.

For example, verbal scaffolding by adults facilitates children's memory skills. Fivush and colleagues (e.g., Fivush & Fromhoff, 1988; Reese, Haden, & Fivush, 1993) have found reliable individual differences in what they call parents' "reminiscing styles," which range from less to more elaborative and are stable across time. These differences have been found to influence children's autobiographical memory for events early in childhood—children whose mothers have a more elaborative style tend to remember more details and understand more about their past experiences (cf., Haden, Ornstein, Eckerman, & Didow, 2001; Haden, Ornstein, Rudek, & Cameron, 2009). Further, training mothers to use a more elaborative style of conversation with their preschool-aged children during a particular event seems to result in better memory as much as 3 weeks later (Boland, Haden, & Ornstein, 2003). Of particular interest to the present work is that the use of *Wh*- questions (e.g., asking who engaged in a particular action or why) is argued to be an especially important characteristic of an elaborative reminiscing style (Hedrick, San Souci, Haden, & Ornstein, 2009). In our research, simply asking a causal question helped children to pull out evidence from a more complex scene. In a way that may parallel the effects seen in children's memory development, this type of scaffolding may have helped children encode the event in a richer, more detailed way that better supported causal inferences.

Other research has shown that verbal scaffolding also influences children's hands-on exploration. Henderson (1984) found that even minimally informative comments from an adult, such as simply expressing enthusiasm, enhanced exploratory play. He presented children ranging from 3 to 7 years of age with several novel items: a drawer box with a number of interesting toys in it; a puzzle box with a number of manipulable items such as switches and springs; and a curiosity board with other manipulable items. Children were either allowed to explore the toys completely independently or had their exploration minimally scaffolded by the experimenter, who commented on their manipulations of the toy by saying things like, "Wow, look at that!" or, "I wonder what's in there?!" Even controlling for baseline levels of curiosity, as well as age, these simple exclamations boosted children's exploration.

More recent work has shown that preschoolers are especially motivated to explore when faced with a causal question that is unanswered by the given evidence (Schulz & Bonawitz, 2007), and simply asking a causal question may well serve to highlight the disconnect between the issue at hand and the child's current causal knowledge. Other work has shown that using simple causal language to describe an event enables 2-year-olds to use their causal understanding (e.g., that pushing two objects together turns a light on) to guide their own actions (Bonawitz et al., 2010). Thus, various forms of scaffolding impact children's exploratory play.

In the current research, children needed verbal framing to help them identify and extract evidence from a noisy scene and make inferences about the causal structure of the event. On a scaffolding account, verbal framing in the form of asking a causal question provided "just enough" guidance to enable children to identify the evidence and solve the problem. As in the cases of memory development and exploratory play, verbal framing allows children to fully capitalize on the cognitive capacities they already possess, but which they may have difficulty applying when left to their own devices.

Especially given parallels to work on scaffolding and exploration, the current research contributes to a broader understanding of how social influences may impact children's hands-on learning. Children clearly learn from observation and exploration, but what exactly they learn and how that information is incorporated into their existing theoretical frameworks is difficult to pinpoint. On the one hand, Klahr and others have shown that whatever young children might be able to learn from hands-on exploration, fourth- and fifth- graders have difficulty designing even rudimentary experiments that would provide informative evidence (Chen & Klahr, 1999; Kuhn, 1989; Strand-Cary & Klahr, 2008). Children appear to need explicit instruction in controlling and manipulating scientific variables to design informative experiments (Strand-Cary & Klahr, 2008).

On the other hand, such explicit instruction seems to be more effective if coupled with hands-on, exploratory learning (Klahr, Triona, & Williams, 2007; Triona & Klahr, 2003). Moreover, giving young children explicit instruction may in some cases actually dampen their natural curiosity and constrain their learning (Bonawitz et al., 2011). Given this apparent tension, perhaps something intermediate between explicit instruction and unscripted exploratory play might help to optimize children's learning. Simply asking children causal questions, as we have done here, is a far cry from explicit instruction but may go far enough to guide children's attention and help them capitalize on what would otherwise be unexploited opportunities for learning.

Parents and teachers play a vital role in scaffolding children's learning by guiding their approach to various everyday problems. As Rogoff (1990) has pointed out, there are countless opportunities in children's everyday lives for "guided participation"—learning opportunities that children may fail to take advantage of without being guided by adults. Of course, verbal framing is only one of many ways to facilitate children's causal reasoning, including presenting a larger set of probabilistic data or more explicitly demonstrating the causal evidence. However, verbally framing the causal problem—particularly by doing something as simple as asking a causal question—may be a particularly efficient way of triggering and facilitating a causal analysis. This approach provides "just enough" guidance to enable children to solve a problem they might otherwise fail to solve, without robbing them of the feeling that they have figured out something for themselves. Just asking a causal question aids causal learning in a minimally intrusive way, while preserving an active role for children in guiding their own learning and ensuring that they are not missing out on learning opportunities. Parents and teachers alike may be able to use simple strategies like probing children during exploration or asking open-ended questions to foster curiosity and help children capitalize on the wealth of learning opportunities available to them.

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REFERENCES

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

Bonawitz, E. B., Ferranti, D., Saxe, R., Gopnik, A., Meltzoff, A. N., Woodward, J., . . . Schulz, L. E. (2010). Just do it? Investigating the gap between prediction and action in toddlers' causal inferences. *Cognition*, *115*, 104–117.

Bonawitz, E. B., Shafto, P., Gweon, H., Goodman, N., Spelke, E., & Schulz, L. E. (2011). The double-edged sword of pedagogy: Teaching limits children's spontaneous exploration and discovery. *Cognition*, *120*, 322–330.

Chen, Z., & Klahr, D. (1999). All other things being equal: Acquisition and transfer of the control of variables strategy. *Child Development*, *70*, 1098–1120.

Fivush, R., & Fromhoff, F. A. (1988). Style and structure in mother–child conversations about the past. *Discourse Processes*, *11*, 337–355.

Gopnik, A., & Schulz, L. (2004). Mechanisms of theory formation in young children. *Trends in Cognitive Sciences*, *8*, 371–377.

Gopnik, A., & Sobel, D. M. (2000). Detecting blickets: How young children use information about novel causal powers in categorization and induction. *Child Development*, *71*, 1205–1222.

Gopnik, A., Sobel, D. M., Schulz, L., & 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*, 620–629.

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

Haden, C. A., Ornstein, P. A., Rudek, D. J., & Cameron, D. (2009). Reminiscing in the early years: Patterns of maternal elaborativeness and children's remembering. *International Journal of Behavioral Development*, *33*, 118–130.

Harris, P. L., German, T., & Mills, P. (1996). Children's use of counterfactual thinking in causal reasoning. *Cognition*, *61*, 233–259.

Hedrick, A. M., San Souci, P., Haden, C. A., & Ornstein, P. A. (2009). Mother–child joint conversational exchanges during events: Linkages to children's memory reports of time. *Journal of Cognition and Development*, *10*, 143–161.

Henderson, B. B. (1984). Social support and exploration. *Child Development*, *55*, 1246–1251.

Inhelder, B., & Piaget, J. (1964). *The early growth of logic in the child*. New York, NY: W. W. Norton.

Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction. *Psychological Science*, *15*, 661–667.

Klahr, D., Triona, L. M., & Williams, C. (2007). Hands on what? The relative effectiveness of physical versus virtual materials in an engineering design project by middle school children. *Journal of Research in Science Teaching*, *44*, 183–203.

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

Kuhn, D., Black, J., Keselman, A., & Kaplan, D. (2000). The development of cognitive skills to support inquiry learning. *Cognition and Instruction*, *18*, 495–523.

Kuhn, D., & Dean, D. (2004). Connecting scientific reasoning and causal inference. *Journal of Cognition and Development*, *5*, 261–288.

Kuhn, D., Garcia-Mila, M., Zohar, A., & Andersen, C. (1995). Strategies of knowledge acquisition. *Monographs of the Society for Research in Child Development*, *60* (Serial No. 245).

Kuhn, D., Katz, J., & Dean, D. (2004). Developing reason. *Thinking & Reasoning*, *10*, 197–219.

Kuhn, D., Schauble, L., & Garcia-Mila, M. (1992). Cross-domain development of scientific reasoning. *Cognition and Instruction*, *9*, 285–327.

Kushnir, T., & Gopnik, A. (2005). Young children infer causal strength from probabilities and interventions. *Psychological Science*, *16*, 678–683.

Madole, K. L., & Cohen, L. B. (1995). The role of object parts in infants' attention to form-function correlations. *Developmental Psychology*, *31*, 637–648.

Madole, K. L., & Oakes, L. M. (1999). Making sense of infant categorization: Stable processes and changing representations. *Child Development*, *71*, 119–126.

Markman, E. M., & Jaswal, V. K. (2003). Abilities and assumptions underlying conceptual development. In D. H. Rakison & L. M. Oakes (Eds.), *Early category and concept development* (pp. 384–402). New York, NY: Oxford University Press.

Mayer, R. E., Lewis, A. B., & Hegarty, M. (1992). Mathematical misunderstandings: Qualitative reasoning about quantitative problems. In J. I. Campbell (Ed.), *The nature and origins of mathematical skills* (pp. 137–153). Amsterdam, The Netherlands: Elsevier Science Publishers.

Reese, E., Haden, C. A., & Fivush, R. (1993). Mother–child conversations about the past: Relationships of style and memory over time. *Cognitive Development*, *8*, 403–430.

Reichenbach, H. (1956). *The direction of time*. Berkeley, CA: University of California Press.

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

Schulz, L. E., & Bonawitz, E. B. (2007). Serious fun: Preschoolers engage in more exploratory play when evidence is confounded. *Developmental Psychology*, *43*, 1045–1050.

Schulz, L. E., & Gopnik, A. (2004). Causal learning across domains. *Developmental Psychology*, *40*, 162–176.

Schulz, L. E., Gopnik, A., & Glymour, C. (2007). Preschool children learn about causal structure from conditional interventions. *Developmental Science*, *10*, 322–332.

Sobel, D. M., & Kirkham, N. Z. (2006). Blickets and babies: The development of causal reasoning in toddlers and infants. *Developmental Psychology*, *42*, 1103–1115.

Sobel, D. M., & Kirkham, N. Z. (2007). Interactions between causal and statistical learning. In A. Gopnik & L. E. Schulz (Eds.), *Causal learning: Psychology, philosophy, and computation* (pp. 139–153). New York, NY: Oxford University Press.

Sobel, D. M., & Sommerville, J. A. (2009). Rationales in children's causal learning from others' actions. *Cognitive Development*, *24*, 70–79.

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*, 303–333.

Stern, E. (1993). What makes certain arithmetic word problems involving comparison of sets so difficult for children? *Journal of Educational Psychology*, *17*, 266–277.

Strand-Cary, M., & Klahr, D. (2008). Developing elementary science skills: Instructional effectiveness and path independence. *Cognitive Development*, *23*, 488–511.

Triona, L. M., & Klahr, D. (2003). Point and click or grab and heft: Comparing the influence of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cognition and Instruction*, *21*, 149–173.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.