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Evidence for an Explanation Advantage in Naïve Biological Reasoning

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Abstract

The present studies compare young children's explanations and predictions for the biological phenomenon of contamination. In Study 1, 36 preschoolers and 24 adults heard vignettes concerning contamination, and were asked either to make a prediction or to provide an explanation. Even 3-year-olds readily supplied contamination-based explanations, and most children mentioned an unseen mechanism (germs, contact through bodily fluids). Moreover, unlike adults who performed at ceiling across both explanation and prediction tasks, children were significantly more accurate with their explanations than their predictions. In Study 2, we varied the strength of cues regarding the desirability of the contaminated substance ($N = 24$ preschoolers). Although desirability affected responses, for both levels of desirability participants were significantly more accurate on explanation than prediction questions. Altogether, these studies demonstrate a significant “explanation advantage” for children's reasoning in the domain of everyday biology.

Keywords

Naïve Biology; Contamination Understanding; Children's Explanations; Children's Predictions

We examine young children's developing causal knowledge structures by focusing on explanation as compared to prediction or judgment. We hypothesize that in some core domains of understanding, children's explanations may more sensitively and richly reveal their understanding than do predictions. Naïve biological reasoning provides an apt domain in which to address this possibility because even young children have access to rich causal knowledge in this domain. Additionally, mature biological reasoning requires the recruitment of unobservable entities and processes to predict and explain more overt phenomena.

One of the primary reasons that the Piagetian account of children's causal knowledge has been replaced in the last three decades was a shift in methods for assessing children's understanding. Piagetian methods depended heavily on analyzing children's explanations, which have been criticized for underestimating children's knowledge (Bullock, Gelman, & Baillargeon, 1982). As Bullock et al. (1982) noted, “Children's explanations for events did

not seem to reflect the same level of causal reasoning as did their judgments or predictions.....The results are, of course, not a surprise to anyone working with preschool-age children. Children are more likely to demonstrate their reasoning in actions and simple choices than explanations” (p. 246). As a result, most contemporary research with young children has focused instead on judgment tasks that ask for predictions.

It seems reasonable that causal predictions could be less demanding and emerge earlier than causal explanations. Causal predictions can be based on detecting causal regularities whereas causal explanations typically require conceptualizing an outcome relative to a more general framework of interpretation. Furthermore, predictions can be manifest in simple yes/no or behavioral judgments whereas causal explanations typically require more extended expression and reasoning. However, although traditional Piagetian investigations failed to portray children's abilities accurately, we propose that it is not explanation itself that is problematic (see also Wellman & Liu, 2007). Explanation tasks can be as effective with young children as those requiring prediction or judgment. Indeed, intriguingly, research in the psychological domain has found that preschool children can provide pertinent explanations in advance of accurate predictions (Amsterlaw & Wellman, 2006; Bartsch & Wellman, 1989), thus showing that young children's explanations can be surprisingly revealing.

We propose that an “explanation advantage” is not confined to psychological reasoning. Specifically, young children's explanations may reveal surprising understandings in several crucial domains, even when their judgments fail to do so. How might it be possible for children to reveal knowledge in explanation tasks, yet fail parallel judgment tasks (that are often thought to be easier still)? One rationale for such a proposal is that a request for explanation often includes an additional piece of relevant information over a request for prediction, namely information about the outcome (Wellman & Liu, 2007). For example, predicting the location of a lost pet potentially involves a much larger problem space than explaining the (discovered) location of that pet. For many explanation tasks, additional information is available because the outcome (to be explained) is known. Thus, in philosophy of science predictions are usually assumed to be more difficult, and a theory receives considerably more credit for predicting phenomena in advance of explaining them (Kuhn, 1962).

Although research on children's psychological reasoning inspired our thinking about a possible explanation advantage, our understanding would be considerably strengthened if extended to another domain. Here we address the issue in the domain of naïve biology, more specifically, children's understanding of contamination. Children's contamination explanations deserve further study in and of themselves, as almost all prior research in this area with young children has elicited predictions but not explanations (Hejmadi, Rozin, & Siegal, 2004; Rozin, Fallon, & Augustoni-Ziskind, 1985; Siegal & Share, 1990; but see Au, Sidle, & Rollins, 1993).

Adults report that contact with a contaminating substance causes an edible substance to become undesirable and offensive (Fallon, Rozin, & Pliner, 1984), even if the contaminating substance is not toxic and leaves only an imperceptible physical or symbolic trace. Although the specific kind of substance, process, or contact considered contaminating is likely to vary across different cultural contexts, sensitivity to contamination is probably universal among adults (Rozin et al., 1985). Intriguingly, contamination awareness develops robustly in early and middle childhood. Although 3-year-olds have shown initial contamination understanding in a few studies (Kalish, 1999; Siegal & Share, 1990), there are clear developmental trends toward greater awareness and understanding (Au, Sidle, & Rollins, 1993). Indeed, in classic studies, contamination understanding was strikingly absent in

young children (Fallon et al., 1984; Rozin et al., 1985) compared to its robust presence in older children and adults (Hejmadi et al., 2004).

The study with the most accurate judgments from very young children is that of Siegal and Share (1990), who found that 3-year-olds predicted that someone would get sick from drinking some juice into which a cockroach had fallen, even if the cockroach was quickly removed. Most other studies are with older children (e.g., children in Kalish, 1999, Studies 1 and 2, averaged 5 years old) and/or have shown markedly less contamination awareness in 3- and 4-year-old children. For example, Au, Sidle, and Rollins (1993) tested 3- to 7-year-olds and found very low levels of contamination understanding before 5 years of age. In their task children were required to rate the desirability of the same beverage in three states (uncontaminated, contaminated with contaminant present, and finally with contaminant removed). They also included a prompting condition in which the researcher suggested that tiny bits of the contaminant might remain in the beverage (after the visible contaminant was removed). Based on the results of desirability ratings, overall both 3- and 4-year olds failed to adjust their ratings for contaminated beverages after the contaminant was added or then removed. That is, young children found the contaminated drinks to be as desirable as ones completely uncontaminated. Although being prompted to think about tiny bits improved their performance slightly, significant improvements in children's contamination sensitivity with prompting were not documented until 5 years of age. Similarly, in another study, when asked to judge characters in story books, 40 percent of 4- and 5-year-olds did not reject juice that came in contact with an insect (Hejmadi et al., 2004).

In total, in research using judgment tasks, 3- and 4-year-old children seem to demonstrate some understanding in a few studies but not in many others. More importantly, in all these studies we have little information regarding the reasoning that young children use to arrive at their judgments. The reasoning of older children seems to include some understanding of invisible contaminants such as germs (Kalish, 1996) or tiny bits of matter (Au, Sidle, & Rollins, 1993; Rosen & Rozin, 1993). Yet even in these studies, children appeal to such constructs only because they are specifically prompted to think in such terms by the experimenters themselves. So we have little sense of children's spontaneous recruitment and use of germs or contaminants even at 5 years of age, and none at 3 and 4 years of age.

Children's explanations, if obtainable, could help elucidate their causal reasoning. Hence, we focus on children's explanations for contamination and illness events to provide insight into their early emerging reasoning and to allow us to compare explanations and predictions in the biological domain. We expected that preschool children's explanations would be particularly revealing of their biological understanding, and indeed, that children's explanations could be more accurate than their predictions.

Although we focus on children, examining the structure and function of explanation speaks to basic cognitive questions studied in psychological studies with adults as well (Keil, 2006; Lombrozo, 2006). Lombrozo and Carey (2006) have recently argued that a psychological function of explanation is to highlight information likely to be useful to future prediction and intervention. And as mentioned earlier, the relationship between explanation and prediction is of importance to philosophy of science (Railton, 1989; Salmon, 1989). Hempel and Oppenheim (1948) state that, "an explanation is not fully adequate unless... it could have served as a basis for predicting the phenomena under consideration".

In Study 1, we developed a method for eliciting biological explanations in young children for the behavior or illness of characters confronted with contaminated foods and beverages. Critically, Study 1 also directly compared children's explanation and prediction for the same events. In Study 2, participants were given two different kinds of explanation and prediction

vignettes to better assess whether an explanation/prediction difference holds up under a variety of conditions.

Study 1

One prior study assessed young children's explanations in the context of contamination reasoning tasks (Au, Sidle, & Rollins, 1993). In that study, children 3 to 7 years old were asked to justify their desirability ratings of an uncontaminated drink, the drink with a contaminant inside it, and the drink with the contaminant then removed. In each case the experimenter asked, "See this picture? You said that you would (insert child's desirability rating on a scale from 1-5) to drink this (beverage). How come?" Both ratings and justifications of their ratings demonstrated a lack of contamination awareness in children younger than 5 or 6. Even with prompting, 3- and 4-year-olds were unable to demonstrate contamination reasoning in their justifications, and only half of the 5-year-olds were able to do so.

Note, however, in this method children were not asked to explain a contamination event so much as to explain their reasoning. In research on children's theory of mind (Amsterlaw & Wellman, 2006; Bartsch & Wellman, 1989), young children are much better at explaining someone's action (X did this; why did X do that?) than explaining their own reasoning (You answered this; how come?). One possibility for the unimpressive performance on the justification questions in the Au, Sidle, and Rollins (1993) study is that they required children to justify their own desirability ratings. This may be more difficult than justifying a contamination-related event. Therefore, in our studies, we asked children to explain events rather than explain their reasoning.

In addition to the primary study comparing children's explanations and predictions, we also added two comparison conditions. A *non-contamination associational control* provided a baseline for better understanding children's explanations in the primary, contamination study. For example, suppose we found that children provide "contamination" explanations in contexts where contamination is not an issue. This would cause us to question the meaning of such explanations; genuine contamination explanations should only (or predominantly) occur in appropriate contamination contexts. An *adult comparison* provided relevant adult baseline information.

Methods

Participants—For the contamination study there were 24 preschool children (*M* age 4,7; range 3,11 to 5,5), 12 males and 12 females, primarily White (83% Caucasian, 13% Asian-American, 4% Latin-American), recruited from a preschool in a Midwestern town. For the adult comparison, 24 college students (*M* age 18 years) from a psychology department subject pool participated, for the non-contamination control 12 additional preschoolers (*M* age 4,1; range 3,4 to 4,11) participated.

Items—Materials included 8 pairs of pictures; four pairs of beverages and four pairs of foods. Items in each pair were matched for size and shape and differed only in type of beverage or food (e.g. pictures of vanilla and strawberry milkshakes in identical glasses). Four pictures of contaminants were used: a dog, grasshopper, leaf, and picnic bench surrounded by grass; see Figure 1. Our focus was children's contamination understanding, not simply evocation of children's disgust reactions. Therefore the stimuli were selected specifically because they are contaminating but not strongly disgusting and thus permit us to assess beliefs about contamination (and not strictly associational disgust). Several of these contamination events have been used in prior contamination research with children (Rozin et al., 1985; Siegal & Share, 1990). Each participant saw all 8 pairs of foods and beverages

once each and the four contaminating pictures twice each, once for the explanation condition and once for the prediction condition. The same pictures were used for the non-contamination control study.

Procedure: Contamination Study—Each participant responded to 4 prediction vignettes (the prediction task) and 4 explanation vignettes (the explanation task)—half received explanation first; half received prediction first. Within the explanation or prediction blocks there were two behavior vignettes and two illness vignettes. The behavior and illness vignettes were paired (e.g., for a given participant, if illness vignettes came first in the explanation condition, they also came first in the prediction condition) and randomized within blocks of 4 explanation and 4 prediction questions.

Contamination events for any beverage or food occurred in one of four ways: a grasshopper jumped in and then jumped out, a dog licked it, a leaf blew into it and was taken out, or it fell on the ground and was picked up again.

In order to make the tasks as comparable as possible, the prediction tasks paralleled the explanation tasks precisely; as shown in the following comparison.

Illness explanation: “I know two kids named Angela and Chris. They are sitting outside having a snack together. Angela has a lemon candy and Chris has a raspberry candy. A grasshopper comes by and looks at Angela's lemon candy. After he looks at the candy he hops away. Then a dog comes by and licks Chris's raspberry candy. After he licks the candy he walks away. Angela eats the lemon candy and Chris eats the raspberry candy. Who eats the lemon candy? Who eats the raspberry candy? The next day Chris gets sick. Why did Chris get sick? Why else?”

Illness prediction: “I know two kids named Angela and Chris. They are sitting outside having a snack together. Angela has a lemon candy and Chris has a raspberry candy. A grasshopper comes by and looks at Angela's lemon candy. After he looks at the candy he hops away. Then a dog comes by and licks Chris's raspberry candy. After he licks the candy he walks away. Angela eats the lemon candy and Chris eats the raspberry candy. Who eats the lemon candy? Who eats the raspberry candy? The next day someone gets sick. Who do you think gets sick?”

The two vignettes provide the same information except that for prediction the outcome was not specified and the child was asked to make a prediction. Notably, both foods or beverages had something happen to them, a contamination action or a proximate non-contaminating action. Which event (contamination or non-contamination) was mentioned first was counterbalanced across illness vignettes. In both illness explanation *and* illness prediction questions participants were told that illness took place; children were asked *who* got sick, not *whether* someone got sick. None of the children spontaneously mentioned that illness would not occur.

Behavior vignettes were slightly different because of their focus on behavioral choice rather than becoming sick. There was a single character who had one preferred option and one well-liked, but less preferred option to choose from. Options got contaminated (and the contaminant removed) in the same ways as in the illness vignettes. For example:

“Brittany is sitting outside. Her mom pours a glass of chocolate milk and a glass of plain milk. It is windy outside and an old brown leaf blows into the glass of chocolate milk. Then Brittany takes the leaf out. Brittany can drink the chocolate milk or the plain milk. Which one should Brittany drink? The chocolate milk or the plain milk?”

In the behavior prediction questions participants were asked which of the items the character *should* eat (as opposed to which of the items the character will eat) to clarify that the question refers to a normative choice rather than an individual's preference or idiosyncratic criterion for what counts as “too dirty”.

For the behavior explanation tasks, the character explicitly chose the less-preferred (uncontaminated) option and participants were asked to provide an explanation for this choice. Explanatory prompts were used following the initial explanation question (“Why is that?” and “Can you tell me more about that?”). These prompts were kept to a minimum and included no additional information from the experimenter. See Appendix A for a listing of examples of all the vignettes, behavioral and illness, explanation and prediction.

The adults received the same procedure as the preschoolers, including being tested individually with the same vignettes and questions.

Procedure for Non-Contamination Control—The non-contamination control was identical to the contamination study except that all evidence of contamination was removed. The dog, grasshopper, and leaf were mentioned as merely walking, hopping, or blowing by.

Transcribing and Coding—Child interviews were audiotaped and transcribed verbatim; the experimenter recorded adult interview responses on paper. Explanations (for the contamination study and the non-contamination control) were coded into 5 categories: restatement, psychological, contamination, other-bodily, and miscellaneous. *Restatements* indicated that the participant answered the explanation question by merely restating the story events (e.g., when asked why a character got sick, responding “because a bug fell in her glass” or “because it fell on the ground”). *Psychological* explanations discussed changing preference or desire (e.g., “maybe she changed her mind and wants this one now” or “this is her new favorite”). We were especially interested in *contamination* explanations. Explanations were coded as contamination if they referred to any of the following: getting sick, having to go to the doctor, mechanisms involving the transfer of contaminating substances, germs, transfer of bodily fluids, or disgust. In the illness condition, because illness was explicitly mentioned, simply restating illness was not coded as contamination but rather as a restatement.

Contamination explanations were further examined to identify a subcategory that explicitly provided a mechanism, such as the transfer of fluids, substances, or germs. These explanations, termed *contamination mechanism* explanations, introduced elements (e.g., germs, slobber) that were never mentioned or depicted in the vignettes. Table 1 provides several examples.

Explanations were coded as *other-bodily* if they referred to bodily processes that did not include contamination (e.g., “he ate too much sugar in the candy,” “she ate too much cookie and that made her tummy hurt”). Because such explanations could be biological or psychological (e.g., perhaps a young child believes eating too much sugar is morally rather than biologically “bad”), we were careful to separate them from those that unambiguously evidenced contamination. Finally, all other responses were coded as miscellaneous (e.g., if children indicated that they did not know why). Explanations that included both restatement and contamination were only coded as contamination explanations. Otherwise, if explanations included a combination of explanation types (e.g., psychological, other-bodily, and contamination), explanations were coded for both. A random sample of 25% of the explanations was coded for reliability by another trained researcher. Inter-rater reliability was 93%.

For the prediction tasks, for behavior prediction vignettes, responses were coded as correct if the participant predicted that the character would choose the less-preferred, non-contaminated option. For illness prediction vignettes, responses were coded as correct if the participant predicted that the character who ate the contaminated option would get sick. Note that the correct prediction for the behavior vignettes (choice of the non-contaminated option) is the opposite of the correct prediction for the illness vignettes (contaminated option).

For the non-contamination control, for the behavior prediction vignettes, responses were coded for the number of favorite options chosen, because preference in the absence of contamination is the obvious basis for making a prediction. Such choices would be incorrect for the contamination study. For the illness prediction vignettes, the first of the two (counterbalanced) options was arbitrarily coded as correct, because there was no other basis on which to distinguish the two choices.

Results

Contamination Study—Given these tasks it would be easy for children to “explain” by simply restating information that was provided in the vignettes. However, that rarely occurred. Moreover, because the stories explicitly mention preferences, favorites, and likes as well as obviously likable things (candy), children might easily explain the outcome-events in terms of psychological phenomena, such as desires, preferences, intentions, and so forth. Instead, as shown in Figure 2, preschoolers in Study 1 gave primarily contamination explanations, 88% of the explanations for the illness vignettes and similarly, 88% of the explanations for the behavior vignettes. Some have proposed that children's initial understanding of biological phenomena is framed in terms of psychological processes (Carey, 1985). However, children's mention of contamination explanations vastly outnumbered their psychological explanations, $t(23) = 10.21, p < .001$.

Explanations that mentioned contamination were considered correct, and predictions consistent with contamination were considered correct. A task (explanation vs. prediction) $\times$ vignette (behavior vs. illness) $\times$ order (explanation first vs. prediction first) repeated measures ANOVA examined the number of correct responses. There was no significant effect of order, but there was a significant main effect for task, $F(1,22) = 20.71, p < .001$, indicating that overall performance was higher for explanation questions ($M = 3.50$ out of 4) than for prediction questions ($M = 2.33$). Notably, performance on prediction questions was not different from chance, $t(23) = 1.36, n.s.$

There was also a significant main effect for vignette, $F(1,22) = 6.66, p < .02$; performance was more accurate on the illness vignettes (collapsing across explanation and prediction) than on the behavior vignettes. However, the main effect was subsumed by a task $\times$ vignette interaction, $F(1,22) = 5.54, p < .05$. As shown on the left of Figure 3, the explanation/prediction difference for children was larger in the behavior condition than the illness condition. However, child performance on explanation questions was significantly better than performance on prediction questions for both behavior, $t(23) = 3.98, p < .001$, and illness vignettes, $t(23) = 3.19, p < .001$.

Contamination explanations often included *contamination mechanisms*. As shown in Table 1, the transmission of germs, disgusting substances, contaminating substances, and dirty substances were all examples of the kinds of contamination mechanisms described by children. As shown in Figure 2, children mentioned such mechanisms in over 60% of their responses; 79% of children provided at least one contamination mechanism explanation. We further coded contamination explanations for the number of new “pieces” of causally relevant information, not stated in the vignette, that the child provided. By definition all

biological contamination explanations include at least one new, relevant piece above and beyond a restatement. However, children often offered multiple pieces of causal information, linked together in a larger explanation. Table 2 gives examples of how causal pieces were tallied. Of the contamination mechanism explanations, 33% included two new pieces of causal information and 12% included 3 or more new pieces of causal information (see Table 2). Sixty-seven percent of children at least once provided an explanation with 2 pieces of causal information.

Individuals' response patterns provide an important complementary analysis. Here we coded children as either consistently correct on the explanation vignettes (4 of 4) or not, and as consistently correct on the prediction vignettes (4 of 4) or not. Twenty of 24 children (83%) were consistently correct on explanation vignettes, whereas only 6 of 24 (25%) were consistently correct on prediction vignettes. This difference is best examined by considering those children ($N = 14$) who were consistently correct on one type of vignette or the other (explanation or prediction) but not both. Of these, all were correct at explanation but not prediction, and none showed the reverse pattern; McNemar's $\chi^2(1) = 18.05$, $p < .001$.

Comparing Adult and Child Performance—It is not clear exactly how best to compare explanation and prediction data statistically. For example, children could provide a great many possible explanations for the events we presented to them (and indeed they did provide 4 or 5 categories of explanations). Thus, the baseline probability of providing any one category of explanation by chance alone must be very small. For the prediction tasks, however, children made binary judgments, so that chance alone provided a 50% opportunity of being correct. These differing baselines complicate precise comparisons. However, in the analyses above our approach was straightforward and conservative; we compared the response proportions regardless of baseline chance responding. Doing this works *against* finding better performance on the explanation task.

Because explanations and predictions are difficult to compare directly, we also compared the performance of children with that of adults. We predicted (based on the “explanation advantage” hypothesis for young children) that there would be age differences on the prediction tasks but not on the explanation tasks. The results are presented in Figure 3.

We conducted a task (explanation vs. prediction) $\times$ vignette (behavior vs. illness) $\times$ age group (children vs. adults) ANOVA on the number of correct responses. Given the purpose of this analysis, only those effects involving age are reported. We obtained a significant main effect for age group, $F(1,46) = 22.43$, $p < .001$. Overall, collapsing across explanation and prediction tasks, performance was higher for adults ($M = 7.88$) than for children ($M = 5.76$). However, as anticipated, this effect was subsumed by a significant task $\times$ age group interaction, $F(1,46) = 16.20$, $p < .001$. Although children performed significantly better on explanation than prediction questions, $t(23) = 4.16$, $p < .001$, adults performed equally well on both, $t(23) = 1.81$, *n.s.* An independent t-test (assuming unequal variance) confirms that although adults performed significantly better than children on the prediction questions, $t(27) = 6.04$, $p < .001$, performance on explanation questions did not differ by age, $t(23) = 2.02$, *n.s.*

There was also a vignette $\times$ age group interaction, $F(1,46) = 7.05$, $p < .01$, indicating that differences in performance between illness and behavior tasks were significantly larger for children than for adults. There was also a task $\times$ vignette $\times$ age group interaction, indicating that the explanation/prediction difference was larger in the behavior condition than the illness condition for children but not for adults, $F(1,46) = 5.23$, $p < .05$.

Non-Contamination Control—Preschoolers in the non-contamination control group appropriately gave different explanations than those in the main, contamination study. Specifically, their explanations were primarily other-bodily ($M = 1.92$) and psychological ($M = 1.33$), with some miscellaneous ($M = 0.75$). Thus, we found no evidence that children gave contamination explanations spontaneously for vignettes that lacked contaminating contact. In fact, none of the children in the non-contamination control group gave any contamination explanations for any of these vignettes.

As expected, illness prediction responses were at chance on the non-contamination control study, $t(11) = 0.43$, n.s. For the behavior prediction questions, children chose the favored option significantly above chance, $t(11) = 3.02$, $p < .01$, which differs markedly from children's performance in the main study, where they selected the favored option *below* chance. When contamination is not at issue, these young children appropriately judged that the protagonist will indeed choose his or her favorite option.

Discussion

Although prior research examining contamination understanding with young children used judgment tasks (Fallon et al., 1984; Kalish, 1996; Rozin et al., 1985; Siegal & Share, 1990), we found that even very young children can and do provide relevant contamination *explanations* that go well beyond information provided in the story events. Preschool children's contamination explanations mention germs and invisible contaminants, and rarely refer to protagonists' psychological states or motives. These data are noteworthy in that, unlike Kalish (1996) or Au, Sidle, and Rollins (1993), we did not prompt children by mentioning germs or tiny particles. Instead, children spontaneously invoked such elements in their explanations.

Young children's explanations demonstrated a level of understanding not often found in young children's judgments. For example, Au, Sidle, and Rollins (1993) found contamination sensitivity in only 25% of 3- to 5-year-olds. In contrast, we found contamination understanding in 88% of 3- and 4-year-olds. We hypothesize that one reason for the relatively sophisticated contamination understanding in our sample is our focus on explanations versus predictions. In our data, preschool children showed greater contamination sensitivity on explanation than prediction tasks, in both the illness and behavior conditions.

Although differing baselines complicate precise comparisons between explanations and predictions, we addressed this issue in two ways. First, we compared the response proportions for explanation and prediction tasks directly, regardless of baseline chance responding. Because children could provide many possible kinds of explanations for the events presented in the task, whereas the binary predictions assure a 50% chance of being correct, ignoring chance baselines works *against* finding better performance on the explanation tasks. Second, we compared adult and child performance on the explanation and prediction tasks. As anticipated, we found that whereas adults performed significantly better than the children on the prediction task, adults and children performed equally well on the explanation task. Thus in comparison to baseline (adult) performance, children also perform significantly better on the explanation tasks than on the prediction tasks.

The prevalence of contamination mechanism explanations is compelling from a theoretical perspective, because they made use of unobservable entities to explain observable outcomes. For example, as a 4-year-old explained, "The grasshopper hopped inside it and the grasshopper is yucky; he might hop in yucky stuff like dirt germs and bug germs." These explanations indicate that children inferred particulars that extended beyond anything visible or mentioned in the vignettes, thereby providing evidence for a sophisticated belief system

about contamination. Moreover, these explanations are unlikely to reflect mere repetition of information provided previously by parents or others (e.g., when children cite “leaf fog,” “grasshopper flavor,” or “doggy-lick germs” as the key causal ingredient). Importantly, these explanations appeared only when appropriate; they were never provided by the associational control group in which no contamination was mentioned.

Study 2

In Study 2 we further test explanation-prediction differences by varying the strength of cues regarding the desirability of the contaminated substances. This is an issue of interest in its own right: Children may be provoked to consider contamination explanations at first only when preference is strongly contravened (e.g., when someone chooses a non-preferred option, as in the explanation vignettes of Study 1). But there is a methodological concern as well. In the prior study children might have done poorly on contamination predictions (and thus worse on predictions than explanations) because preference alone is such a strong cue for predicting behavior. Consequently, predicting on the basis of contamination would require overriding a baseline tendency to predict on the basis of preference. For these reasons, in Study 2 we investigated how differences in the desirability of the food or beverage options may affect children's explanations and predictions of contamination.

We included only behavior vignettes, because they most clearly focus on preferences and desires for the items. Two conditions were included. One condition (*different-desirability*) included the same behavior vignettes used in Study 1: they described one preferred beverage (or food) that got contaminated and a different, less-preferred beverage (or food) that did not get contaminated. The other condition (*same-desirability*) included two identical beverages (or foods), one of which got contaminated and the other not. In both conditions we contrasted prediction questions with explanation questions. The same-desirability vignettes provide an especially strong test of possible differences between explanation and prediction, because there are no competing demands. For these vignettes, both foods are the same and therefore are equally desirable; the only difference between them is that one is contaminated and the other is not. If same-desirability vignettes make predictions easier, then the same-desirability condition provides a still more stringent test of the comparison between prediction and explanation.

Methods

Participants—Participants were 24 preschool children (M age 4,2; range 3,5 to 4,11) from a preschool in a Midwestern town, 12 males and 12 females, a sample that was primarily White (88% Caucasian, 12% Asian-American). None of the children in Study 2 had participated in Study 1.

Items—Materials included 8 pairs of pictures that were primarily the same as in Study 1. Two additional pictures (iced tea and peanuts) were included.

Procedure—As in Study 1, participants were read short vignettes that required them to reason about contamination-related behavior. The vignettes were accompanied by pairs of pictures of the foods or beverages. For Study 2, participants were given two different kinds of explanation and prediction behavior vignettes. In one condition (same-desirability), participants were asked to explain or predict contamination-related behavior involving the same type of food or drink (e.g., two candies); in the other condition (different-desirability), participants were asked to explain or predict contamination-related behavior involving foods or drinks of different desirability (e.g., grape juice, water). Each participant responded to 4 prediction questions and 4 explanation questions. For the prediction vignettes in Study 2, participants were asked which one the character *would* drink (or eat), instead of asking about

which one the character *should* drink (or eat), as in Study 1. Given similar responses across studies this insures that children's predictions were not dependent on the use of a specific term.

Half the participants received the explanation task first, half received the prediction task first. For explanation and prediction there were two *same-desirability* vignettes that included the same type of food or beverage (e.g., two cheese crackers) and two *different-desirability* vignettes that included different foods or beverages (e.g., one vanilla milkshake and one iced tea). The same- and different-desirability vignettes were paired together (e.g., for a given participant, if same-desirability vignettes came first in the explanation condition, they also came first in the prediction condition) and randomized in pairs within blocks of 4 explanation and 4 prediction questions.

For the same-desirability condition, one of the foods or drinks got contaminated and the other did not. For the different-desirability condition, as in Study 1, the preferred option got contaminated.

Transcribing and Coding—Interviews were audiotaped, transcribed verbatim, and coded for the same categories as in Study 1: restatement, psychological, contamination, other-bodily, and miscellaneous. Contamination explanations were again further examined for contamination mechanism explanations as well. For the prediction vignettes, responses were coded as correct or incorrect. Inter-rater reliability was 96%. Disagreements were resolved by discussion.

Results

Consistent with Study 1, preschool children gave primarily contamination explanations for contamination-related behavior ($M = 3.37$ out of 4 vignettes), followed by psychological ($M = 0.42$) and other-bodily explanations ($M = 0.21$). Contamination mechanisms were also often provided ($M = 2.29$); 79% of the children gave at least one. Even for same-desirability vignettes, most children (75%) described at least one contamination mechanism. Of the contamination mechanism explanations, 79% included two or more new pieces of causal information. Fifty-eight percent of children gave an explanation with two pieces of causal information at least once.

A task (explanation vs. prediction) $\times$ condition (same-desirability vs. different-desirability) $\times$ order (explanation first vs. prediction first) repeated measures ANOVA was conducted on the number of correct responses. There was a significant main effect for task, $F(1,23) = 19.38$, $p < .001$, indicating that overall performance was higher on explanation questions ($M = 3.67$ out of 4) than on prediction questions ($M = 2.41$); see Figure 4. There was also a significant main effect for condition, $F(1,23) = 21.65$, $p < .001$, indicating that overall, performance was more accurate on the same-desirability items (collapsing across explanation and prediction) than on the different-desirability items. Moreover, as is clear in Figure 4, the task $\times$ condition interaction was also significant, $F(1,23) = 21.65$, $p < .001$, indicating that the difference between explanation and prediction was smaller in the same-desirability condition than in the different-desirability condition. Nonetheless, the explanation-prediction difference was significant in each condition considered separately: same-desirability: $t(23) = 2.07$, $p < .05$; different-desirability: $t(23) = 5.47$, $p < .001$.

Again, each child was classified as either consistently correct or not, on each type of vignette (same-desirability explanations, different-desirability explanations, same-desirability predictions, different-desirability predictions). In each case, to be classified as “consistent,” a child had to respond correctly on both trials (2 of 2). For the same-desirability condition, 21 of 24 children (88%) were consistently correct for the explanation

questions, and only 14 of 24 (58%) were consistently correct for the prediction questions. Furthermore, of the 9 children who were consistently correct at explanation or prediction but not both, *all* were correct at explanation but *not* prediction; McNemar's $\chi^2(1) = 6.13, p < .01$. For the different-desirability questions, 22 of 24 children (92%) were consistently correct for the explanation questions, and only 7 of 24 (29%) were consistently correct for the prediction questions. In this condition, 15 children were correct at explanation but not prediction and none showed the reverse pattern; McNemar's $\chi^2(1) = 13.07, p < .001$. Thus, on average and for individual children, there was significantly better performance on explanation than prediction questions for both same- and different-desirability items.

Discussion

Consistent with Study 1, preschool children gave primarily contamination explanations for contamination-related behavior. Additionally, children gave significantly more accurate explanations than predictions, for both same-desirability as well as different-desirability vignettes. Not only do the results from Study 2 confirm better performance on explanation questions than prediction questions for vignettes of different desirability (as found in Study 1), they also provide additional evidence in support of an explanation advantage. Potentially, different-desirability scenarios might have overestimated differences between explanation and prediction by (a) making contamination predictions relatively difficult (because to be correct children's predictions had to override information about preferences), and/or (b) making explanations especially easy (because the actions to be explained were especially anomalous in that the character chose not to partake of his or her preferred food). These possible differences were eliminated in the same-desirability vignettes, but here too children were better at contamination explanations than predictions.

General Discussion

Causal knowledge structures allow people to generate predictions and explanations (Carey, 1985; Keil, 1989; Wellman & Gelman, 1992). With children, predictions have been much more extensively studied than explanations. Yet explanations may be especially important because they express the child's more extended reasoning about a phenomenon. Satisfactory explanations do more than connect observable events with observable outcomes; they invoke unseen entities and structures (Gopnik & Wellman, 1994). In our studies, young children's explanations proved revealing of just these sorts of concepts. Most importantly, children proved better at *explaining* than *predicting* contamination.

Although differing baselines complicate precise comparisons, we addressed differences in the baseline probability of providing accurate explanations and predictions in two ways, by: (a) comparing the response proportions for explanation and prediction tasks directly (which provides a conservative test, given the higher baseline chance of responding correctly to the prediction questions), and (b) comparing children's performance on the explanation and prediction tasks to that of adults. Both of these comparisons showed an explanation advantage in young children's responding. Beyond accuracy alone, explanations more richly revealed children's extended causal reasoning.

Of course it is worth considering if our prediction tasks were just spuriously difficult. Perhaps some of our prediction tasks (behavior prediction tasks) were especially difficult in presenting a conflict between reasoning consistent with the character's preference and reasoning consistent with contamination understanding. When forced to choose between preference and contamination understanding, children may be conflicted, and so often choose the preferred option. Much research shows that young children often emphasize an actor's desires when predicting his or her action (Bartsch & Wellman, 1995; Wellman & Woolley, 1990). However, crucially, we also found an explanation/prediction difference in

the same-desirability condition of Study 2, even though the food and drink options were matched in terms of desirability. Additionally, we argue that the explanation advantage cannot be attributed to task demands for verbal competency; as the results obtained are precisely the opposite of what would be predicted based on verbal task demands (Clark, 1983). Note also that children had no difficulty understanding prediction questions parallel to those used throughout our research in the non-contamination control study (within Study 1).

Finally, young children's difficulty on the prediction task in the present studies replicates their relative difficulty with contamination understanding in classic studies that elicited children's judgments (Fallon et al., 1984; Rozin et al., 1985) or desirability ratings (Au et al., 1993). However, a few prior studies have demonstrated apparently sophisticated contamination understanding in preschool children with prediction tasks (Siegal & Share, 1990). One possible explanation for this discrepancy is that in the contamination prediction tasks reported in Siegal and Share (1990), the correct (contaminated) item was the only one of the two options that experienced an unusual event. This confound may have increased children's tendency to choose the correct item, thereby contributing to children's high levels of performance. In our prediction tasks, we controlled for such influences in two ways. In our behavior prediction task, the correct choice was the less salient, less desirable (uncontaminated) option (Study 1) or one of two equally preferable options (Study 2). In our illness task, instead of having something happen to only one character's food or beverage, an unusual action happened to *each* of the two foods or beverages, one involving contamination (e.g., licking) and one involving a proximate non-contaminating action (e.g., looking). With these design features, both 3- and 4-year-olds had difficulty making accurate predictions.

One important feature of our data is that even 3-year-olds supplied biological explanations for contamination, appealing to invisible substances and entities. Carey (1985) has proposed that young children understand and explain biological events and outcomes in terms of psychological principles such as desires and beliefs. In our explanation tasks children easily could have done so, especially when the scenarios emphasized protagonists' preferences. Nonetheless, the overwhelming number of contamination explanations given by preschoolers focused on bodily processes, contamination, and imperceptible causal mechanisms.

There is a lack of consensus in the literature over what constitutes a genuinely “biological” mechanism (Au & Romo, 1999; Kalish, 1996; Solomon & Cassimatis, 1995). Here we use the term *mechanism* to refer to an unobserved, inferred link whereby an observed cause produces an observed effect. A contamination mechanism further refers to causes with distinctively bodily “active ingredients” (e.g., “germs,” “saliva”) rather than distinctively psychological contents (e.g., preferences). The mechanism is still more elaborate if it mentions some sort of transfer of those active ingredients. This definition does *not* require that preschool children have a scientifically-based understanding of bacteria, germ propagation, or the like. Hence we would not wish to claim that preschoolers (or even adults for that matter) have a full-fledged scientific biological theory (Au & Romo, 1999). Nonetheless, the contamination mechanism explanations provided by these young children included many inferred, imperceptible features. To elaborate, their explanations made use of *unobservable* entities (e.g., “doggy slime,” “grasshopper flavor,” “leaf fog,” “doggy germs,” “poison from the grasshopper's skin”), none of which were mentioned or depicted in the scenarios we provided. Children's explanations also often mentioned inferred methods of transmitting contaminants. For example, one 3-year-old explained, “It fell in the dirt, there's little animals in there, little animals climb in there,” and a 4-year-old explained that “The grasshopper has a color on its skin that got in the pop and made it poisonous; maybe the grasshopper hopped in and left green stuff.”

Not only do these explanations invoke constructs never mentioned in our procedure, they invoke constructs that are unlikely to have been specifically provided by parents. It is unlikely, for example, that parents have specifically mentioned “grasshopper juice,” “leaf powder,” or “doggy-lick germs.” Of course, children probably have heard their parents and preschool teachers refer to germs, poison, and dust. So children's explanations were not created *de novo* by the children. Still, that children recruited these concepts appropriately and specifically to explain novel contamination events provides evidence for a generative ability to reason about contamination. Moreover, they creatively embellished how things like germs might exert their (unobserved) influence (e.g. “little animals climb in there”). Intriguingly, however, the sort of reasoning evident in children's explanations seldom informed their predictions. As yet, little is known regarding how general constructs versus specific events, adult input and socialization, and other factors contribute to the development of causal understanding including contamination sensitivity. However, the content of children's explanations suggests an important role for their own productive inferences in constructing causal knowledge.

Contamination beliefs are likely to vary across diverse cultural contexts (Hejmadi et al., 2004; Raman & Gelman, 2004; Toyama, 2000), yet sensitivity to contamination *per se* is probably universal among adults (Rozin et al., 1985). These considerations suggest that an additional direction for future research would be to explore more systematically how cultural input interacts with children's own explanatory reasoning in shaping causal learning. Contamination causality provides an informative forum for research more generally exploring cultural influences on causal-explanatory learning.

Recently, Keil and colleagues have described the explanations of both adults and children as lacking complexity and sophistication (Keil, Rozenblit, & Mills, 2004; Mills & Keil, 2003). They characterize ordinary causal explanations as shallow and often “lacking a clear sense of a specific mechanism” (Wilson & Keil, 1998). Furthermore, the typical concept of cause referred to in everyday, lay explanations is “not much more than that of something that brings about, in some way, the phenomena that we seek to explain” (Wilson & Keil, 1998). Although we acknowledge that everyday, lay explanations typically lack the rich, scientific detail of an expert, our data nonetheless reveal a level of explanatory “depth” in quite young children. As shown in Tables 1 and 2, children consistently went beyond restatements to provide two or more new pieces of causal information, referring to plausible mechanisms such as the transfer or contact of “germs,” “bugs,” “tiny animals,” and so on.

Having demonstrated an “explanation advantage” in young children's biological reasoning, akin to that apparent in some studies of children's psychological reasoning, it is worth speculating how such a counterintuitive advantage could be. Intuitively, it seems more sensible that there could be a *prediction advantage*, where causal predictions could be easier than causal explanations. For one thing, predictions can be achieved with simple, even nonverbal judgments, whereas explanations (of the sort we have studied) require more demanding verbal articulation. More substantively explanations seem to require a deeper level of analysis than predictions. Arguably, causal predictions can be based on detecting specific causal regularities (the relation between X and Y), and thus achieved on the basis of observing statistical regularities between specific events. In contrast, causal explanations typically require invoking more general explanatory principles (the *why* of an explanation). Moreover, many cognitive accounts assume that, development proceeds from specific to abstract. Altogether, then, standard views of development would seem most compatible with the view that explanations would develop after specific causal inferences or predictions.

Nonetheless, when we consider specific examples, we see that explanations can certainly be easier than predictions. Compare two scenarios. In a prediction scenario, we have a new

hybrid car left overnight (in Michigan) in January. Prediction question: “What's going to happen to the car?” (Shrug.) In the parallel explanation scenario, we have the same unfortunate car *and* an outcome; for example, it is covered in ice. Explanation question: “Why is there ice on the car?” (“It got so cold that condensation froze on it.”)

As captured here and argued by Wellman & Liu (2007), explanation can be difficult because there are multiple possibly relevant causes and frameworks to consider. But explanation has a clear advantage as well: the outcome of the causal chain is specified. In this sense, explanation is a form of postdiction (as contrasted to prediction). Knowing the outcome of the relevant causal chain constrains what the reasoner need consider. Outcome information significantly reduces the problem space much as reverse engineering does. It is far easier to engineer a radically new sort of hybrid car if one has a working car to disassemble and analyze. Reverse engineering also occurs in explanation, when taking apart a causal chain to see how it works. Instead of having to work out the forward causal chain, with its large number of possible outcomes, working out the reverse causal chain from a known outcome narrows the possibilities. This is why in the philosophy of science, it is an axiom that more credit accrues to theories that can make accurate predictions of as-yet-unobserved phenomena and not merely explain observed phenomena after the fact. Explanations are easier for scientific theories because there has already been a peek at the results.

Consideration of children's cognition also offers at least one additional reason for why explanations are easier than predictions, at least for young children. Early in life children are better at thinking and talking about the past than the future (e.g., Sachs, 1983). Whereas explanations focus on the past, predictions require considering the future. A developmental precedence for explanations over predictions would align sensibly with this well-demonstrated childhood precedence of thinking about the past over thinking about the future. Indeed, it may be that thinking about the past is easier for young children than thinking about the future because, just as in the above scenarios, the past has in fact occurred and in that sense is more constrained than the future.

The reasoning we have outlined for why children demonstrate an explanation advantage has several implications. First, such an advantage, as we construe it, implies that children assemble causally connected knowledge. Hence, it could appear in certain causally-rich domains of understanding (e.g., naïve biology and naïve psychology) but not for just any causal events. Second, because the advantage also rests on the relative uncertainty of postdiction given an outcome and prediction in the face of multiple outcomes, this implies there should be ways to manipulate the probabilities so as to introduce greater uncertainty for explanation than prediction. For example, a task in which explanations require an assessment of relative probabilities (a grasshopper jumps in the soda and a dog licks the soda; why does the boy who drinks the soda get sick?) may make explanation harder.

Finally, a natural extension of our analysis suggests that explanations may play a crucial role in children's learning. How so? To the extent that explanations are more constrained than predictions (as just argued), leading to more accurate answers, this increased accuracy could helpfully constrain causal learning. Moreover, to the extent that children's explanations are initially more sophisticated than their predictions (as we have demonstrated), explanations may represent children's most advanced theoretical reasoning and thus provide an important platform for further learning. The nature of the explanations we observed, in appealing to unobserved explanatory entities and processes, could also be important for learning of the sort described by a naïve theory perspective on cognitive development. To the extent that explanations appeal to theoretical unobservables, they engage children in the important interplay between data and theory that leads to theory change. Clearly our studies were not designed to investigate explanation-based mechanisms for causal learning, but given our

results, this becomes an important topic for further research. Indeed, there is mounting evidence that children's causal explanations may in fact constitute a mechanism for advancing causal learning and the acquisition of knowledge (Bartsch & Wellman, 1989; Callanan & Oakes, 1992; Chi, DeLeeuw, Chiu, & LaVancher, 1994; Gopnik & Meltzoff, 1997; Lombrozo, 2006; Siegler, 2002). For example, requiring children to explain events enhances learning over simple feedback about correctness of their predictions (e.g., Amsterlaw & Wellman, 2006; Siegler, 1995).

In sum, the present studies advance what is known about the development of contamination concepts by carefully examining children's explanations. More generally, our data on children's explanations provide clear support for an advantage of explanation over prediction in the realm of naïve biology. More generally still, evidence for an explanation advantage in young children's reasoning suggests a possible crucial role for explanation in children's causal knowledge structures, and in their learning of such causal knowledge. In these ways, although we have studied the development of explanatory knowledge in children, our proposals and results can inform current psychological research on explanation with adults (e.g. Keil, 2006; Lombrozo, 2006), support proposals regarding the important role of explanation in theory (Gopnik & Wellman, 1994), and link to accounts of explanation in the philosophy of science (Hempel & Oppenheim, 1948; Pitt, 1988).

Appendix A: Study 1, Sample explanation and prediction vignettes: Behavior and illness

Behavior Explanation

I know a boy named Tom. Tom really likes grape juice. Grape juice is Tom's favorite thing to drink. Tom also likes apple juice. But Tom doesn't like apple juice as much as grape juice. What kind of juice does Tom like the most, grape juice or apple juice?

Tom is sitting outside. His mom pours a glass of grape juice and a glass of apple juice. Then, a grasshopper jumps into the glass of grape juice. After a minute the grasshopper jumps out of the juice and hops away. Tom can drink the apple juice or the grape juice. Tom decides to drink the apple juice.

Why did Tom drink the apple juice? He really likes grape juice, so why did he drink the apple juice? Why else?

Behavior Prediction

I know a girl named Brittany. Brittany really likes chocolate milk. Chocolate milk is Brittany's favorite thing to drink. Brittany also likes plain milk. But Brittany doesn't like plain milk as much as chocolate milk. What kind of drink does Brittany like the most, chocolate milk or plain milk?

Brittany is sitting outside. Her mom pours a glass of chocolate milk and a glass of plain milk. It is windy outside and an old brown leaf blows into the glass of chocolate milk. Then Brittany takes the leaf out. Brittany can drink the chocolate milk or the plain milk.

Which one should Brittany drink? The chocolate milk or the plain milk?

Illness Explanation

I know two kids named Michael and Veronica. They are sitting outside having a snack together. Michael has a vanilla milkshake and Veronica has a strawberry milkshake. Then

Michael puts his glass of vanilla milkshake next to him on the ground. After sitting for a minute, he picks his milkshake up and puts it on the table. Then, an old brown leaf blows into Veronica's strawberry milkshake. Then Veronica takes the leaf out. Michael drinks the vanilla milkshake and Veronica drinks the strawberry milkshake. Who drinks the vanilla milkshake? Who drinks the strawberry milkshake?

The next day Veronica got sick. Why do you think Veronica got sick? Why else?

Illness Prediction

I know two kids named Jane and Heather. They are sitting outside having a snack together. Jane has a sugar cookie and Heather has an oatmeal cookie. Then, Jane's sugar cookie slips off the table onto the ground. Jane picks it up and puts it back on the table. Then a dog walks by and looks at Heather's oatmeal cookie. After looking at the cookie, the dog walks away. Jane eats the sugar cookie and Heather eats the oatmeal cookie. Who eats the sugar cookie? Who eats the oatmeal cookie?

The next day someone gets sick. Who do you think gets sick?

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Fig. 1.
Studies 1&2, pictures of contaminants.

Fig. 2.

Study 1: Children's explanations for behavior and illness items. *Note:* Contamination mechanisms are a subset of the contamination explanations.

Fig. 3. Children's explanations and predictions (responses indicating biological contamination) for Study 1.

Table 1
Study 1, sample biological mechanism explanations

Germ-transmission	Disgust-transmission	Contaminating substance transfer	Dirt or dirty substance transfer
"Because this one has the germs from the dog on it. Dog took a lick, they spread germs on each other and the boy gets sick"	"If she eats it then there's mud, because the chocolate chip cookie fell In the mud, there would be mud in her mouth, since there's also bugs In mud, that's gross"	"Maybe the grasshopper has a color on its skin that got In the pop and made it poisonous. Maybe the grasshopper hopped in and left green stuff"	"It fell in the dirt. there's little animals in there; little animals climb in there"
"Because the dirt is dirty and she doesn't want to get sick. Dirt has yucky germs on it and that's where the worms are"	"Cause there's doggy lick In there; because it would taste gross"	"Cause he knew the grasshopper jumped in and jumped out 'Cause it doesn't taste good; that kind of grasshopper flavor doesn't taste good"	"Because the leaf came in and fogged the milk and got it all dirty. It just dirty cause the leaf came in"
"Because he doesn't want to get dog germs, they will make him definitely sick. Dogs have dirty tongues like worms"	"Because of the leaf, cause they are yucky for you. You get icky stuff in your tummy"	"He wanted the grape because he wouldn't want doggy slime in his mouth. He would have to go to the doctor"	"Because the chocolate milk was dirty cause the leaf fell In. the leaf can crack and a piece can fall off"

Table 2
Analysis of explanations in terms of causal “pieces”

0 pieces	“Because the grasshopper jumped in”	Restatement of information provided In the vignette
1 piece	“Because the grasshopper went in, because he has dirty feet”[1]	Child supplies novel information relevant to contamination, information not provided in the vignette (i.e., “dirty feet”)
2 pieces	<p>“Because of the grasshopper, I think he got a cold [1] and he brought him the cold” [2]</p> <p>a. “The dog licked it with his dirty tongue, cause there are germs on the dog and in the dog’s mouth”</p> <p>b. “Because she didn’t want to get germs in her mouth from the ground. There are germs in the dirt if someone spits in it”</p> <p>c. “Because the grape juice is going to have germs, because the grasshopper went in and it has germs on its legs and feet”</p>	Child supplies two pieces of additional novel information relevant to contamination, information not provided in the vignette, often indicating method of transmission (i.e., “he brought him the cold”)
3 or more pieces	<p>“Because the grasshopper is dirty [1], cause it bounces on the around [2], the around is dirty [3], cause it’s brown and full of tiny animals [4]”</p> <p>d) “Because the leaf came in and fogged the milk and got it all dirty, it’s just dirty because the leaf came in”</p> <p>e) “Because it’s yucky, because the grasshopper jumped in there, because he might have did bathroom in there. Oh that’s gross!”</p> <p>f) “The leaf has leaf flavor on it. Leaf flavor has special germs that got in the pop when the leaf fell in there. Then she drank it and got sick from the leaf germs”</p>	Child supplies at least three pieces of additional novel information relevant to contamination, information not provided in the vignette, often indicating a coherent causal link of transmission (i.e., “the ground is dirty, cause it’s brown and full of tiny animals”)

Additional examples of explanations with 2 (a, b, c) and 3(d, e, f) causal pieces. All explanations from children In Studies 1–2.