Bridging the gap: Children's developing inferences about objects' labels and insides from causality-at-a-distance

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Abstract

Previous research had shown that 4-year-olds were likely to extend labels and internal properties of objects based on those objects' causal properties even in light of perceptual conflict. All of these studies presented causal relations that acted on contact. This study examined the effect of adding causality at a distance to perceptual conflict tasks. We found that 4- and 5-year-olds preferred to extend labels to objects with similar perceptual properties over objects with similar causal properties when those properties conflicted and the causation was at a distance. When children were asked to make inferences about internal properties instead of labels, they were much more likely to make causal responses, and we found development between 4- and 5-year-olds. We interpret the results as support for the idea that young children understand mechanism as part of causation, and suggest further investigations relating causality, internal properties, and object labels. **Keywords:** Causal inference, categorization, causal mechanisms, cognitive development

Causation ties our world together. If we know two things are causally related, we can use the cause to make the effect occur. We also know to expect effects when causes occur, and we know how to trace responsibility for outcomes we wish to encourage or discourage.

But this knowledge does not come easily. Many relations among events appear to be causal but are not. For instance imagine you walk up to a vending machine, put your money in, and press the button for a drink. A moment later, two things happen simultaneously: A drink comes out of the machine and lightning strikes your car. The next day, you are walking by the machine, and you are thirsty. Presumably, you would not be reluctant to push the button for a drink, even if it looks like rain.

How do you recognize that one relation is causal and the other is coincidence? One possibility is that through repeated exposure, you have learned that pressing these kinds of buttons on these kinds of machines produces drinks and not weather events. Another possibility is that you imagine the mechanism involved – the connection between cause and effect – and use this to determine the most likely causal structure to explain what was observed. The former account focuses on covariation, the latter on mechanism.

There is a debate in the causal reasoning literature about which one of these plays a greater role in causal reasoning. Covariation has been modeled formally with great success (e.g., Cheng, 1997; Griffiths & Tenenbaum, 2005) and researchers have shown that learners reason in line with the expectations of these models. But it is also clear that covariation information alone is insufficient to explain all of human causal reasoning (e.g., Ahn, Kalish, Medin, & Gelman, 1995; Bullock, Gelman, & Baillargeon, 1982; Shultz, 1982), and that such reasoning relies at least in part on an understanding of mechanism.

Children and The Blicket Detector

Covariation accounts often explain away apparently mechanism-based reasoning by saying that it was gained from experience. This makes children, who have much less experience, especially relevant to the debate. It also makes it crucial to develop a method which minimizes the effect of experience, by presenting children with novel, non-obvious causal properties of objects. Such a method was developed by Gopnik and Sobel (2000), who introduced children to a *blicket detector* (Figure 1), a machine that lights up and plays music when some objects (usually labeled *blickets*) are placed on it. The blicket detector has been used to investigate three primary questions in children's causal inference: (1) Their understanding of the relation between causes and labels; (2) Their understanding of the relation between causes and internal properties; (3) Their causal reasoning in general. We will examine each of these programs briefly below.

Figure 1: The blicket detector used in the present research

Causes and Labels Several research programs have suggested that children understand that category membership involves understanding more than common perceptual features of objects (e.g., Gelman & Markman, 1986, 1987; Kemler-Nelson et al., 1995, 2000). Kemler-Nelson et al. (1995) found that preschoolers appreciate that artifact categorization is more influenced by common function than perceptual similarity. But there had been little work examining causal properties directly. To this end, Gopnik and Sobel (2000) investigated whether preschoolers extended novel object labels based on shared causal properties. Children were shown sets of blocks, some of which activated a machine. One of the blocks that did so was then labeled a "blicket" and children were asked to extend the object label to another object. We will focus on their *conflict* condition, in which children had to choose among a block that looked the same, but had failed to make the machine go, (a perceptual response) a block that looked different but had also made the machine go (a causal response) or a block that had neither property (a distracter). Children made causal and perceptual responses about equally. Critically, they made causal responses more often than in a *control* condition, in which each object was held over the detector while the experimenter visibly pressed a button for certain objects, which activated the machine. Here, objects were associated with the machine's activation, but were clearly not the cause.

Other investigations using more tightly-controlled procedures (e.g., Nazzi & Gopnik, 2000) revealed developmental differences: three-year-olds mostly generated perceptual responses while 4-year-olds made significantly more causal responses, but not always above chance.

Causes and Insides Several research programs have also demonstrated that children understand links between category membership and inferences about objects' internal properties. Keil (1989) found that kindergarteners understand that an animal that has undergone external cosmetic changes (but remained the same on the inside) retained its original identity. Gelman and Wellman (1991) demonstrated that preschoolers recognized that insides were important in determining what category an object belongs to. Specifically, they found that 4-year-olds recognized that changing the insides of certain objects like a dog or an egg would fundamentally change the object's category membership, but changing the insides of other "insides-irrelevant" objects like a jar would not. Four-year-olds also inferred that removing an "insides-relevant" object's insides would change its function. This is critical to understanding the relation between causes and insides.

Sobel et al. (2007) found that 4-year-olds but not 3-year-olds related causes and insides in light of competing perceptual information. Children were shown the blicket machine (although it was not labeled as such) and a set of objects like those shown in Figure 2 (which were adapted from the Nazzi & Gopnik, 2000, stimuli). Children observed that two of the blocks (objects AI and BI in Figure 2) activated the machine and other object (object A in Figure 2) did not. They were then shown that object AI had an internal part and were asked which other object had the same inside. Four-year-olds chose object BI more often than chance, and significantly more often than 3-year-olds, who relied on perceptual similarity.

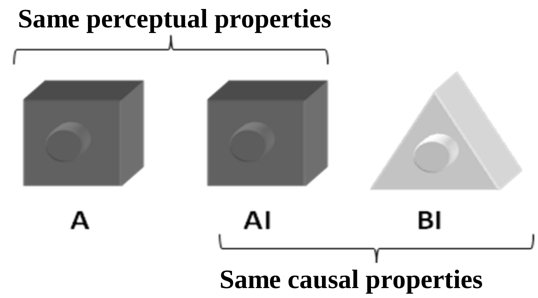

Figure 2: Schematic representation of stimuli used in the perceptual conflict task.

Causal Reasoning in General The blicket detector has also been used to investigate children's causal inferences more generally, often suggesting that preschoolers and even younger children have quite sophisticated abilities (e.g., Gopnik et al., 2001). Recent investigations have used the detector to examine children's understanding of causality at a distance. (e.g., Kushnir & Gopnik, 2007) Distance causality is of particular importance to understanding how children integrate of covariation and mechanism information: it draws attention to mechanism while also leaving it unspecified.

Following Hume (1750/1963), many researchers claim that spatial contiguity is necessary for our understanding of causality. But there are exceptions. For instance, Michotte (1963) found that contact was not always necessary for the perception of physical causation. As long as an object influenced another's "radius of action" adults perceived causal relations. Anecdotally, children appreciate the causality of remote controls, light switches, and many social events, which all present causal relations without contact.

Shultz (1982) asked children about cases in which distance cues conflicted with mechanism information. Most children consistently attributed power to causes consistent with their mechanistic knowledge instead of choosing the most similar cause or the one closest in time or space. For instance, when choosing which of two tuning forks was causing a box to resonate, children would choose the one that was vibrating, even if it was furthest from the box.

Shultz's results were consistent for all of his age groups between ages 5-13, but throughout his experiments, preschoolers did not appear to understand these mechanisms as well. Bullock, Gelman, and Baillargeon (1982) found that the use of mechanism information generally changed for children between ages of 3 and 5. Specifically, 5-year olds were more likely than younger children to describe the mechanism involved in causality at a distance.

Using the blicket detector, Schulz and Gopnik (2004) found that children seem to have default domain-based ideas about how the machine will work, but these can be overturned relatively easily. They found 4-year-olds could learn to make the machine go through verbal commands, crossing the border between physical and psychological causation. Kushnir and Gopnik (2007) found that if an object was held over the machine, rather than placed on the machine when it activated, 4-year-olds would trade off this spatial contiguity information against probability information. They would accept distance causation, but only if it were much more deterministic than an alternative, contact-based cause.

Insides, Labels and Causality-at-a-Distance

Our review so far suggests that 4-year-olds have a firm understanding of the relation between causal properties of objects and their insides, and less of a well-defined understanding of the relation between causal properties of objects and their labels. But all of these investigations have presented children with causal relations that act with spatial contiguity. The goal of the present study was to replicate some of these investigations, presenting children with causal relations that act at a distance. Further, there are few investigations that directly contrast what children know about causes and labels with what they know about causes and insides. We will make this comparison.

Experiment 1

In this experiment we gave children a perceptual conflict task about extending labels or internal properties, but added distance to the causal relations. Children were shown the causal properties of objects, then asked to infer which objects shared a common label or which objects shared a common internal property. The causal properties conflicted with the perceptual properties (as shown in Figure 2). Critically, the causal property of each object was determined by holding the object over a machine, which activated in response to this action for certain objects, rather than placing objects directly on the machine. We examined 4-year-olds to compare with established findings using similar procedures with contact causality (Nazzi & Gopnik, 2000; Sobel et al., 2007). However, since 4-year-olds had some difficulty with causality at a distance in Kushnir and Gopnik's experiments, which used a similar method, we also examined 5-year-olds.

Participants The final sample included 34 four-year-olds (10 girls, M = 53.60 months, range = 47-62 months) and 32 five-year-olds (13 girls, M = 70.80 months, range = 63-77 months). One additional 5-year-old was tested, but excluded due to experimenter error. About half the children were tested in a laboratory environment, while other children were tested in a quiet room at their preschool. Half of the children were randomly assigned to the *insides* condition and the other half were assigned to the *labels* condition. There were no significant differences in age between the conditions.

Materials The machine was an 8" x 6" x 3" box made of black plastic with a white top (see Figure 1). If an object activated the machine, green LEDs wired into the top of the device illuminated and the machine placed a novel melody. The machine was designed to be activated surreptitiously via a remote held under the table, hidden from the child.

Four different sets of three blocks were used (see Figure 2). The same blocks were used in both conditions. Each block had a small but obvious "door" on one side – a hole had been drilled into it, and then plugged with a dowel of the same color as the block. Each set consisted of three blocks: A, AI, and BI. Blocks A and AI were identical except that AI had a small red ball hidden inside of the hole. This red ball was only visible when it was being explicitly demonstrated to the child – the rest of the time the 'door' was closed. Block BI was a different shape and color than A and AI, but otherwise analogous. For instance, one set consisted of two purple egg-shaped blocks (one with a red inside) and a white triangular block with a red inside. Four additional blocks, all different in shape and color, were used in the pretest.

Pretest Children were first asked to point at four blocks based on their size and color, without touching them. Children who did not point correctly, (n = 1) or who touched the blocks, (n = 1) were asked to try again. No children failed the pretest after this second try. This pretest established that children would interact with the experimenter and that they would be asked to point (and not touch) objects.

Insides condition. In this condition, the children were first introduced to the machine: "This is my machine. Some things make it go, and some things don't." No reference was made to labels or mechanisms. The first set of blocks was placed on the table between the child and the machine, and the efficacy of each object was demonstrated one by one, from left to right. Each block was held individually four to six inches over the machine for ~3 seconds. For object A, the machine was not activated. For objects AI and BI, the machine was activated for the entire time that the block was held over the machine. This was achieved by pressing a button on the machine's remote, which was kept hidden under the table. Each block was then demonstrated a second time with the same results. The locations of the blocks were varied within subjects in pseudo-random order, so the blocks were seen in a variety of orders and locations.

After the child had seen each object twice, the experimenter pointed out the doors and opened the door on object AI to point out that it contained "a little red thing inside." The experimenter then placed the door back on object AI and asked the child, "Can you point to the other one with a little red thing inside?" The child's response, either A or BI, was recorded, and the next set of three blocks were introduced. Order of presentation of the sets of blocks was counterbalanced between subjects.

Labels condition This condition was identical to the insides condition except for one key change: Instead of opening up object AI to show the red ball inside, children were simply told that object AI was "a blicket," and were asked to point to the other blicket. Note that children were not told that "blickets make the machine go."

Post test In both conditions, after children were given the four test trials, they were given an opportunity to activate the machine themselves. They were given two new blocks (A and B). They were shown and told verbally that one block (A) had a red thing inside and one (B) did not (in the insides condition), or told that one block (A) was a blicket and the other (B) was not (in the labels condition). Then both blocks were placed in front of the child (location counterbalanced) and they were asked "Can you make the machine go?" Their action was recorded. If object A was held over the machine, the machine was activated for as long as it was held there. If children made this response initially, object A was removed and object B was left on the table. Children were asked whether they could activate the machine with this object.

Results and Discussion The dependent variable was the number of trials on which each child made causal responses (range from 0-4). These data are shown in Table 1. Gender, object placement, and trial order had no significant effect on responses. Our analysis did not find that any one set of blocks was more likely to elicit a causal response than any other.

Table 1: Causal Responses in Experiment 1

	Number of Causal Responses						
	0	1	2	3	4	Mean	SD
4-year-olds							
Insides (n = 17)	5	5	1	4	2	1.59	1.46
Labels (n = 17)	12	1	0	2	2	0.94	1.56
5-year-olds							
Insides (n = 16)	2	0	3	1	10	3.06	1.44
Labels (n = 16)	10	0	0	3	3	1.31	1.78

Children's causal responses were analyzed by a 2 (age group) x 2 (condition) ANOVA. This revealed a main effect of age, F (1, 62) = 5.75, p = .020, Partial η^2 = .085, as well as a main effect of condition, F (1, 62) = 9.70, p = .003, Partial η^2 = .135. No significant interaction was found. Simple effect analysis revealed that 5-year-olds were more likely to make causal responses in the insides condition than 4-year-olds, $t(31)$ = -2.92, p < .05 with a Scheffé correction, and that 5-year-olds were more likely to make causal responses in the insides condition than the labels condition, $t(30)$ = 3.06, p < .05 with a Scheffé correction.

Since these data potentially had a bimodal distribution, we wanted to consider these simple effects nonparametrically as well. (Interactions could not be tested this way.) The distribution of 5-year-olds' responses on the insides condition was different from that of 4-year-olds, Mann-Whitney U = 62.50, z = -2.74, p = .007. This was not the case in the labels condition, Mann-Whitney U = 122.00, z = -0.60, *ns*. Similarly, 5-year-olds' distribution of responses differed between the labels and insides condition, Mann-Whitney U = 59.50, z = -2.76, p = .008. In this analysis, 4-year-olds' distributions showed a marginal significant difference, Mann-Whitney U = 98.50, z = -1.70 p = .114. These results were similar to the parametric analysis.

We also considered whether each group's responses differed from chance performance. The distribution of responses was significantly different from chance in each case, Multinomial test for each of the four groups, p < 0.001.

On the posttest, all children held object A over the machine (which resulted in the machine activating). When only object B was on the table, 63 out of the 66 children held it over the machine or failed to perform any action. Three children did bring it in contact with the machine. One placed it on directly; two dropped it, presumably by accident.

Finally, we also (informally) compared these data to published reports of similar experimental procedures that used contact causality instead of causality at a distance (i.e., Nazzi & Gopnik, 2000; Sobel et al., 2007). In both the labels and insides condition, 4-year-olds were less likely to make causal responses when the effect occurred at a distance than when the object came into contact with the machine. In the present insides condition, 5-year-olds responses resembled 4-year-olds' responses for the analogous procedure using contact causality, while 4-year-olds' responses resembled 3-year-olds' responses for contact causality. In the labels condition, both 4- and 5-year-olds made mostly perceptual responses, suggesting that they did not relate the causal properties of the objects to their category membership, and the distinction between contact and distance causality might be even more important.

Two speculations can be made from these data. The first is that preschoolers find causality at a distance harder to process than causality that involves contact, which makes these tasks more difficult than the analogous studies using contact causality. The second is that children might find the relation between objects' causal properties and their category membership weaker than the relation between objects' causal properties and their insides. We will expand on this issue in the general discussion.

Experiment 2

A concern with Experiment 1 is that 4-year-olds might not consider causality at a distance in any circumstance. If so, then 4-year-olds should fail to use causality at a distance regardless of whether a perceptual conflict exists. Here, 4-year-olds were given a *neutral* version of the labels and insides conditions, in which no perceptual conflict existed. We predicted that children would tend to choose the causal object, ruling out this simple explanation.

Participants The final sample included 34 four-year-olds (16 girls, M = 54.28 months, range = 47-62 months) One child was excluded due to experimenter error. Children were randomly assigned to two conditions: labels (n = 17) and insides (n = 17). Children were either tested in the lab or in a quiet room in their preschool.

Materials and Procedure This experiment used the same materials and procedure as Experiment 1, with one change: Each block set contained blocks that were equally dissimilar in appearance. In each set, the three blocks were all the same shape but different colors. For instance, one set contained an orange cube, a yellow cube, and a white cube.

Thus, the child was faced with a different choice than in Experiment 1. Rather than having to choose between a block that looked the same and a block that had similar causal properties, children had to choose between an object that had a similar causal property and a distracter. This procedure does not test children's ability to override a perceptual conflict, but rather their ability to recognize that causal properties are at all relevant for categorization or inference.

Results and Discussion No significant effects were found for gender, testing location, or order of presentation of the blocks. Also, no set of blocks or order of presentation elicited significantly more causal responses than the others.

The mean number of causal responses in the insides condition was 2.63 (out of 4, SD = 1.20); the mean in the labels condition was 3.13 (out of 4, SD = 1.09). An ANOVA showed no difference in children's' performance between conditions. F (1, 30) = 1.52, *ns*. A nonparametric comparison of the two distributions also revealed no difference. Mann-Whitney U = 96.00, z = -1.276, *ns*. In both conditions, children made significantly more causal responses than would be predicted by chance. Multinomial tests, p = .012 for the insides and, p < .001 for the labels condition.

The results of Experiment 2 were compared with those of the 4-year-olds in Experiment 1 through a 2 (Condition) x 2 (Experiment) ANOVA. We found a main effect of experiment, F (1, 62) = 23.55, p < .001, Partial η^2 = .28. Simple effect analysis revealed that in both the insides and labels conditions, 4-year-olds were more likely to make causal responses in Experiment 2 than Experiment 1, t(31) = -2.21 and -4.64, p = .034 and p < .001 respectively. Nonparametric analyses were consistent with these results: the distributions of responses between the two experiments were different for both the insides and labels conditions, Mann-Whitney U = 78.50 and 39.50, z = -2.12 and -3.65, p = .037 and p < .001 respectively.

These data suggest that 4-year-olds (and presumably older children as well) could relate the causal properties of objects when they were presented at a distance to those objects labels or internal properties in the absence of a perceptual conflict. Four-year-olds appear to recognize the efficacy of causes at a distance, but such recognition might not be enough to extend a common inside or label in the face of perceptual similarity; we will consider this in the general discussion.

General Discussion

When children were asked to extend novel labels or internal properties based on objects' causal properties, we found that adding distance to the mechanism through which objects produced their causal efficacy influenced inferences, particularly when objects' causal properties conflicted with their perceptual appearance. In the insides condition, some 4-year-olds but most 5-year-olds related causal properties at a distance to insides. This is similar to the developmental difference between 3- and 4-year-olds found by Sobel et al. (2007) when the causal property involved contact. In the labels condition, both 4- and 5-year-olds responded based on perceptual features when asked to extend labels, suggesting that only older children connect category membership to those objects being able to produce causal relations at a distance. When no perceptual conflict was present, 4-year-olds could relate causal properties at a distance to both objects' common labels and insides, suggesting that the perceptual conflict was critical.

There are two open questions from this study. First, why are children better able to relate causality at a distance to insides than labels? One possibility is that the perceptual conflict is stronger for labels than it is for insides. Extensive research has shown that children expect the perceptual properties of an object to predict its label (e.g., Landau, Smith, & Jones, 1988). When Gelman and Wellman (1991) gave children a conflict between common category membership and common external perceptual features, 4-year-olds used category information to make inferences about objects' insides. This suggests that children treat causes and insides as more strongly related than causes and labels. This would also explain the difference in performance between Gopnik and Sobel's (2000) categorization task, in which 4-year-olds responded at chance on a similar labels task, and Sobel et al. (2007), who found that 4-year-olds were above chance at a similar task involving insides.

In support of this possibility, we speculate that children's understanding of the mechanisms behind this causal efficacy is critical and potentially developing. Both Bullock et al. (1982) and Shultz (1982) found that children's general understanding of causal mechanisms developed between ages 3-5. An object's insides might serve as a placeholder for that mechanism - for example, Sobel et al. (2007) found that 4-year-olds understood that moving an object's internal property to another object also transferred its causal efficacy. Children might understand such mechanistic knowledge before they understand that it might also define a category – the inference required in the label condition.

The second open question is why young children find causality at a distance difficult, when their understanding of contact causality seems relatively sophisticated. One possibility is that children simply reject all causality at a distance, and dismiss the covariation as coincidence. Experiment 2 suggests this possibility is unlikely. However, 4-year-olds were far from making entirely causal responses. Overall, these data, suggest that young children accept causality at a distance, but their understanding of it is probably tenuous (consistent with Kushnir & Gopnik, 2007).

In the perceptual conflict task, children must weigh two competing pieces of covariation information against each other: external perceptual similarity and causal properties.

Clearly, external perceptual similarity is related to category membership: objects that look alike tend to be members of the same category or have other properties in common. But an adult-like understanding of conceptual structure relies more on underlying causal features of objects than just their external properties (e.g., Murphy & Medin, 1985). As a result, children might make perceptual responses because of "dumb attentional mechanisms" (e.g., Smith et al., 1996) that bias the child to weigh external features heavily, and can only overcome that bias when the information they observe is sufficiently salient to do so.

So, instead of rejecting causality at a distance, it could be that when children observe covariation information that is consistent with their mechanism knowledge, they treat that evidence as more salient. As a result, contact causality, which 4-year-olds more likely understand, is treated as critical for categorization and inferences about insides. Causality at a distance is not understood as well by 4-year-olds (Bullock et al., 1982; Kushnir & Gopnik, 2007; Shultz, 1982), and as such might not be treated as important as external perceptual similarity for these judgments. This offers an explanation for why 5-year-olds differ in their responses to the insides and labels conditions. The mechanism knowledge they are learning allows them to realize that the covariation information presented by the detector is critical for other non-obvious properties of those objects. When asked about a non-obvious property (i.e., insides), children might connect that knowledge more easily than when asked about a label, which stands for common category membership and which implies shared non-obvious properties. Put more simply, inferences about labels might require one more step than inferences about insides.

To conclude, these data suggest that children can integrate covariation and mechanism information. But when the causal mechanism is not well-understood (as in the case of causality at a distance) the covariation information presented by the detector is less important given an alternative – perceptual similarity. But as children acquire mechanism knowledge, they may start to bridge the gap.

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