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Young children revise explanations in response to new evidence

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Abstract

Revising explanations when faced with new evidence is essential to the learning process. Two studies with 3- to 6-year-olds examined the capacity to generate and revise explanations in response to different kinds of evidence within and across domains. In Study 1 (N = 60) children were presented with new evidence about an alternative individual preference that was inconsistent with children’s prior beliefs. In Study 2 (N = 60) the new evidence was biological rather than psychological. The data demonstrate that children are more likely to first explain inconsistent than consistent psychological outcomes and that children revise explanations for inconsistent outcomes in response to new evidence, both within and across domains.

*Keywords:* belief revision; cognitive development; causal reasoning; explanation; explanation revision; scientific reasoning
Young children revise explanations in response to new evidence

A substantial and influential body of research has documented that children’s explanations provide insight into the development of causal knowledge and conceptual understanding (Callanan & Oakes, 1992; Frazier, Gelman, & Wellman, 2009; Hickling & Wellman, 2001; Keil, 2006; Keil & Wilson, 2000; Schult & Wellman, 1997; Wellman, Hickling, & Schult, 1997). Yet explanations reveal more than just what children know; new research supports the proposal that explanation plays an important role in scaffolding the learning process (Bonawitz, van Schijndel, Friel, & Schulz, 2012; Brewer, Chinn, & Samarapungavan, 1998; Legare, 2012; Lombrozo, 2006) and may be developmentally privileged (Legare, Wellman, & Gelman, 2009; Wellman & Liu, 2007). If explanation is a powerful and widespread mechanism for acquiring knowledge and constructing new understanding, children should not only be motivated to seek out and construct explanations for the complex world around them; they should also flexibly revise explanations in response to new information.

Explaining why a phenomenon occurs is one of the fundamental objectives of the scientific process and an important goal of science education (Gelman, Brenneman, Macdonald, & Román, 2010). Despite the widely documented educational benefits of generating explanations (Amsterlaw & Wellman, 2006; Chi, 2000; Chi, DeLeeuw, Chiu, & LaVancher, 1994; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Crowley & Siegler, 1999; deLeeuw & Chi, 2003; Lombrozo, 2006; McEldoon, Durkin, & Rittle-Johnson, 2012; McNamara, 2004; McNamara, O'Reilly, Rowe, Boonthum, & Levinstein, 2007; Rittle-Johnson, Saylor, & Swygert, 2008; Williams & Lombrozo, 2010; 2013) and the acknowledged importance of generating explanations for cognitive development (Gopnik, 2000; Wellman, 2011), the cognitive process by which explanations contribute to the discovery of new information and the construction of
more sophisticated knowledge has only been studied recently in early childhood (Legare & Lombozo, 2014; Legare, Zhu, & Wellman, 2013; Walker, Lombozo, Legare, & Gopnik, 2014). In the current studies we investigated the kinds of events that motivate explanation-revision in early childhood.

We hypothesize that explanation is most efficacious when harnessed to understand inconsistency and that children flexibly revise their explanations in response to new information. If explanation plays a role in acquiring new information and constructing new understanding, then learners should explain the observations that have the greatest potential to teach them something new; namely, those that are inconsistent with respect to their current knowledge and thus motivate further information seeking. We operationalize consistent outcomes as events that conform to expectations based on prior knowledge, and inconsistent outcomes as events that violate expectations based on prior knowledge. Biases to explain inconsistent and ambiguous information could aid in learning by focusing children on events that challenge current causal knowledge and provoke additional, amended causal reasoning by increasing awareness of uncertainty and the potential for multiple interpretations of the same information (Bonawitz, Fischer, & Schulz, 2012; Legare, 2012; Stahl & Feigenson, 2015).

This proposal finds support in recent work examining the biases that motivate children to provide explanations. In a series of studies with preschool children, Legare and colleagues have examined the kinds of events that prompt explanation and how explanatory biases provide insight into the function of explaining (Legare, 2012; Legare, Gelman & Wellman, 2010; Legare & Gelman, 2014). The results of these studies indicate that outcomes inconsistent with prior knowledge are especially powerful triggers for children’s explanations, and that the explanations children provide for inconsistent outcomes refer to unobserved causal mechanisms and internal
causal properties, overriding perceptual biases. This suggests that explanation provides children with the opportunity to articulate new hypotheses for events that, at first, disconfirm their current state of knowledge (Legare, 2014; Walker, Williams, Lombrozo, & Gopnik, 2012). Although these studies did not directly measure learning, the data they present are consistent with the proposal that children’s explanations play an active role in the learning process and provide an empirical basis for investigating the mechanisms by which children’s explanations function in the service of discovery.

Despite evidence that inconsistent outcomes trigger causal explanations more often than consistent outcomes (Legare et al., 2010), it is unclear why inconsistency motivates children to generate explanations. One possibility is that children may interpret such information as ambiguous or as supporting multiple interpretations. New information may appear superficially to be inconsistent but in fact opens up the hypothesis space to alternative interpretations. When faced with information that appears inconsistent with prior knowledge (e.g., an actor chooses not to select their favorite food), there are multiple potential explanations (e.g., actor’s preference could have changed, something about the particular favorite item that was undesirable). Thus, inconsistency is inherently ambiguous and it may be this ambiguity or uncertainty that motivates the bias to explain inconsistent outcomes (Foster & Keane, 2015; Lipton, 2004).

Notably, merely attending to inconsistency does not always lead to explanation revision (Bindra, Clarke, & Shultz, 1980; Dunbar & Klahr, 1988; Fay & Klahr, 1996; Kuhn, 1989; Vosniadou & Brewer, 1992, 1994). For example, one can ignore inconsistent evidence, reject it, declare it beyond the scope of the theory in question, or postpone coming to terms with the new evidence (Chinn & Brewer, 1993). Encouraging children to explain inconsistency may serve as a critical mechanism for integrating and reconciling discordant or ambiguous information with
existing theories and may reduce engagement in theory-preserving strategies like rejection and postponement.

But how might the process of explaining inconsistent information generate amended beliefs? One possibility is that explaining encourages learners to formulate and entertain hypotheses they would not have spontaneously considered otherwise. Generating hypotheses in the service of explanation may influence the kinds of hypotheses formulated, as well as their impact on cognition (Bonawitz et al., 2012; Legare & Lombrozo, 2014; Walker et al., 2014; Walker et al., 2012). In particular, both children and adults have strong intuitions about what makes something a good explanation (Bonawitz & Lombrozo, 2012; Frazier et al., 2009; Lombrozo, 2007), and explanation may promote the production of hypotheses that are judged as informative.

The capacity to actively revise existing hypotheses when faced with new information is an essential component of knowledge acquisition. Although explanation revision is widely acknowledged as core features of cognitive development (Gopnik & Schulz, 2007), little is known about the role explanation may play in this process. Given the bias to explain inconsistent outcomes (Legare et al., 2010), children may be particularly receptive to new information surrounding an inconsistent event, respond flexibly to new information, and incorporate this information into their developing explanatory frameworks. It is also possible, however, that incorporating new information into their previous explanations may pose a considerable cognitive challenge for young children. For example, when faced with new information potentially relevant to a previous explanation for an inconsistent outcome, children may use their first explanation as an ‘anchor,’ and this will serve as a bias against incorporating new evidence into their explanations (Tversky & Kahneman, 1974). It may also be the case that
the tendency towards a confirmation bias may inhibit the capacity to incorporate new evidence into existing explanations. In the current research we examine the extent to which constructing a causal explanation for inconsistent outcomes informs and constrains children’s capacity to formulate and revise explanatory hypotheses.

We are especially interested in the capacity to incorporate new information from within and across different intuitive domains into existing explanations. Prior research indicates that children use intuitive, domain-specific, foundational theories to organize information, interpret observations, and reason about novel situations (Wellman & Gelman, 1992). Human actions can have psychological, physical or biological causes, and thus provide an optimal context for studying the children’s explanations across domains. Research into children’s explanations of human actions showed that young children are capable of differentiating appropriately between naïve physical, psychological, and biological explanations (Schult & Wellman, 1997; Wellman, et al., 1997). Additionally, evidence that inconsistency with prior knowledge serves as an explanatory trigger has been limited to the physical domain (Legare et al., 2010). We examined the extent to which this explanatory bias generalizes to other early-emerging and developmentally-privileged domains of understanding.

In prior work on children’s reasoning across domains, Schulz, Bonawitz, and Griffiths (2007) investigated how causal learning integrates the constraints provided by domain-specific theories with domain-general statistical learning. They found that children more readily incorporate new evidence into their theories within rather than across domains, and only 4- and 5-year-olds learned from cross-domain evidence. Other research has demonstrated that when children do not have any additional evidence, they use domain-specific explanations. However, when they are presented with domain-inappropriate evidence, they use cross-domain evidence to
construct causal explanations and even predictions (Schulz & Gopnik, 2004). When presented with appropriate evidence, children were able to overrule prior domain-specific inferences and use the new evidence to construct causal explanations and predictions across domains. In the current studies, we examined the capacity to revise explanations when presented with different kinds of evidence (consistent vs. inconsistent).

**Current studies**

The objectives of the current studies were to examine (a) the extent to which the bias to explain inconsistency generalizes to other early-developing, core domains of knowledge (i.e., naïve psychology and naïve biology), both within (Studies 1) and across (Study 2) domains and (b) the extent to which children revise their explanations to accommodate new evidence for inconsistent outcomes (Studies 1 & 2). In Study 1, we examined children’s explanations in response to inconsistent versus consistent events in the domain of naïve psychology and investigated the capacity to modify explanatory hypotheses for inconsistent outcomes when presented with new evidence. Study 2 extended upon Study 1 to include new information about inconsistent outcomes from another core domain, naïve biology.

**Study 1**

The objectives of Study 1 were to examine (a) whether inconsistent events act as explanatory triggers within the psychological domain and (b) the extent to which children incorporate additional information into their explanations for inconsistent events. Using an experimental paradigm modified from Legare et al. (2010), children participated in a training task about the preferences of two actors (i.e., liking and disliking apples). Next, children participated in three experimental trials: a confirmation trial, a test trial, and a new evidence trial (Table 1).
For each trial, dependent variables included which outcome children explained first and the content of their explanations for consistent versus inconsistent outcomes. In the new evidence trial, we examined the extent to which participants revised their previous explanations in response to new evidence about the inconsistent outcome (e.g., new preference information). We predicted that children would be especially motivated to explain inconsistent outcomes, provide explanations that reflect the preferences of the actors, and flexibly revise their explanations for inconsistent outcomes when faced with new (preference-based) information.

**Method**

**Participants**

Ten 3-year-olds ($M$ age = 3.5; range = 3.0-3.9), twenty 4-year-olds ($M$ = 4.4; range = 4.0-4.9), fifteen 5-year-olds ($M$ = 5.3; range = 5.0-5.9), and fifteen 6-year-olds ($M$ = 6.2; range = 6.0-6.8) were recruited from a large city in the American Southwest. Participants were primarily Euro-American and from middle-class families. Forty boys and 20 girls participated in the study.

**Materials**

Video stimuli were created for each of the four segments in the experiment. All videos depicted two female actors wearing differently colored t-shirts (i.e., Actor 1 wore a blue shirt and Actor 2 wore a red shirt). Videos were presented on a 15” laptop screen.

**Procedure**

Each participant was tested individually in a 15-minute session. The child was seated next to an experimenter, and both viewed the video stimuli on a laptop placed on a table in front of them. The experimenter told each child that the video was about people the experimenter knew and that the video would be paused throughout for questions. Each session consisted of a
training task and three experimental trials: a confirmation trial, a test trial and a new evidence trial (Table 1). Following each question, children were given an opportunity to follow-up their response (e.g., can you tell me anymore about that?” If children failed to provide a response, the experimenter restated the question.

**Training task.** Each child was first presented with a video clip of the two female actors (one in blue and the other in red) stating their preferences about apples. Actor 1 stated her preference first by saying, “I like apples. Apples are my favorite food. I like to eat apples.” Actor 2 stated her preference second by saying, “I don’t like apples. Apples are not my favorite food. I don’t like to eat apples.” The video was then paused and the experimenter asked the child about the individual preferences of the actors (i.e., “Which one of my friends likes apples?” and “Which one of my friends doesn’t like apples?”) to test for comprehension. If the child answered these questions correctly, the experimenter continued with the rest of the procedure. If the child answered incorrectly, the video was replayed and the questions were repeated. If the child answered incorrectly a second time, the study was terminated.

**Confirmation trial.** Next, the child was presented with a video in which the same actors were seated behind a table. On the table was a plate with two apples on it. The actors simultaneously behaved in a manner that was consistent with their previously stated preferences. Actor 1 (who had stated a preference for apples) reached for an apple at the same time as Actor 2 (who had stated a dislike for apples) crossed her arms across her chest. The video was then paused and the participant was asked a series of questions that began with a general explanatory prompt (i.e., “Why did that happen?”). If no answer was provided or if the answer given did not explain the behavior of both actors, the experimenter asked specific questions to ensure that the actions of both actors were explained (e.g., “Why did the girl in blue do that?” and “Why did the
girl in red do that?”). The purpose of the confirmation trial was to examine the content of children’s explanations and to ensure that the child understood the previously stated preferences of each actor. We predicted that children would be equally likely to explain the behaviors of either actor first since they both behaved in a manner that was consistent with their stated preferences.

**Test trial.** Following the confirmation trial, the child participated in the test trial. Prior to the start of the video, the child was told that she would see the same people as in the previous videos, but that this time they would have two new apples. In this video, Actor 1 (who liked apples) behaved in a manner consistent with her stated preference (i.e., reaching for an apple) and Actor 2 (who disliked apples) behaved in a manner that was inconsistent with her stated preference (i.e., she too reached for an apple). As in the confirmation trial, the actors reached for the apples simultaneously. The video was paused mid-reach, and the experimenter asked the explanatory prompt (i.e., “Why did that happen?”). If no answer was given or if the answer did not explain the actions of both actors, the experimenter asked specific questions in counterbalanced order to ensure that the actions of both actors were explained (e.g., “Why did the girl in blue do that?” and “Why did the girl in red do that?”). We predicted that children would be more likely to explain the inconsistent event first in response to the explanatory prompt.

**New evidence trial.** Prior to the start of the new evidence trial, the experimenter told the child, “Let’s keep watching!” in order to communicate that this video was a continuation of the previous video. The video was continued from where it had been paused (with both actors’ hands suspended over the apples), and Actor 1 continued to act in a manner consistent with her stated preference by grasping the plate with the two apples and pulling it towards herself. As Actor 1
moved the apples away, a cookie that had been occluded by the plate of apples came into view, and Actor 2 (who had behaved inconsistently with her stated preferences in the test trial by reaching towards the apple) reached for and picked up the cookie. This new information, that Actor 2 was reaching for a cookie rather than an apple, provided an alternative explanation for Actor 2’s behavior during the test trial. As with all previous trials, the participant was asked the explanatory prompt (i.e., “Why did that happen?”) and, if necessary, asked to explain the behavior of each actor in the video (e.g., “Why did the girl in red do that?” and “Why did the girl in blue do that?”). We predicted that children would revise their previous explanation of Actor 2’s behavior based on this new information.

Table 1

*Study 1 Design*

<table>
<thead>
<tr>
<th>Coding</th>
<th>Actor 1</th>
<th>Actor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statement of Preference</td>
<td>Likes apples</td>
<td>Does not like apples</td>
</tr>
<tr>
<td>Confirmation Trial</td>
<td>Reaches for an apple</td>
<td>Does not reach for an apple</td>
</tr>
<tr>
<td>Test Trial</td>
<td>Reaches for an apple</td>
<td>Reaches for an apple</td>
</tr>
<tr>
<td>New Evidence Trial</td>
<td>Retrieves apples on plate</td>
<td>Retrieves a cookie that was</td>
</tr>
<tr>
<td></td>
<td>(no new evidence)</td>
<td>occluded from view behind</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the plate in the previous</td>
</tr>
<tr>
<td></td>
<td></td>
<td>trial (new evidence)</td>
</tr>
</tbody>
</table>
The entire session was videotaped and transcribed verbatim. For each trial of the experiment, children’s responses were coded for which actor’s behavior was explained first and for the content of the explanations. Content codes varied by trial, with later trials allowing for more variable explanations. We now explain the content codes by trials.

**Confirmation trial.** Responses were categorized as either *individual preference* or *non-explanatory*. Answers that acknowledged the preference of the actor (e.g., “She likes apples.”) were coded as *individual preference*. Answers that were irrelevant to the task or “don’t know” responses were coded as *non-explanatory*.

**Test trial.** As in the confirmation trial, responses for the consistent event were categorized as *individual preference* or *non-explanatory*. Responses for the inconsistent event were coded as *individual preference*, *non-explanatory* or *new preference*. *New preference* explanations indicated that the actor had changed her previously stated preference (e.g., “She likes apples now.”).

**New evidence trial.** As in previous trials, responses for the consistent event were coded as *individual preference* or *non-explanatory*. Responses for the inconsistent event were coded as *individual preference*, *non-explanatory*, *new preference*, or *new goal*. *New goal* explanations stated that Actor 2 had not revised her previous preference (a dislike of apples), but instead had an additional preference (e.g., a preference for cookies). Thus, the new goal category included explanations that described Actor 2’s reach for the cookie. For example, “Oh! She was going for the cookie!” and “The red lady did not like apples so she took the cookies.”

To examine children’s ability to revise explanations, we examined the consistency of the explanatory categories between trials. If no change occurred from one trial to the next, children were assigned a score of 0; if children provided a different explanation from one trial to the next,
they were assigned a score of 1. For example, if a child provided an individual preference explanation in the confirmation trial and a new preference explanation in the test trial, she was given a score of 1. There were a total of three trials (with two possible changes).

Inter-rater reliability was established using a randomly selected sample of 25% of the explanations provided. Reliability was calculated in all trials for whether or not the participants first explained Actor 1 or Actor 2 (93% agreement) as well as the type of explanation provided (79% agreement). All of the Kappas for this coding fall within or near perfect (.81 and above) levels (Landis & Koch, 1977).

Results

First we present data on which outcome children explained first, in response to the general explanatory prompt, then the content of their explanations in response to all questions, and finally changes in their explanations across trials. All analyses were first run with age as a factor, and when no effects of age were found, this factor was removed from subsequent analyses.

First explanation

To assess whether an inconsistent event served as an explanatory trigger, we compared the proportion of children who provided an explanation to the general explanatory prompt for the inconsistent action first to the proportion of children who provided an explanation for the consistent action first.

In the confirmation trial, which was designed to ensure that children could explain the actions of the two actors when both were acting consistently, a Chi-square Test of Independence revealed that a significantly higher proportion of children first explained the action of the actor who liked apples (Actor 1; 53%) than of the actor who did not (Actor 2; 20%), $\chi^2 = 11.2, (1, N =$
The remaining children (37%) referred to both actors simultaneously. Similarly, in the test trial, the Chi-square analysis revealed that a significantly higher proportion of children first explained the inconsistent event (92%) than the consistent event (4%), \( \chi^2 = 91.9, (1, N = 60), p < .001, \) Cramer’s V = .87. The remaining children (4%) referred to both actors simultaneously. In the new evidence trial, significantly more children first explained the inconsistent event (Actor 2, 57%) than the consistent event (Actor 1, 3%), \( \chi^2 = 26.8, (1, N = 60), p < .001, \) Cramer’s V = .47. The remaining children (40%) referred to both actors simultaneously.

**Content of explanations**

**Confirmation trial.** For Actor 1 (who liked apples), 98% of the explanations were coded as individual preference; the remaining responses were coded as non-explanatory. For Actor 2 (who dislikes apples), 93% of the explanations were coded as individual preference; the remaining 7% of the responses were coded as non-explanatory. Given that the number of non-explanatory responses was small, rendering small cell counts an unreliable Chi-square approximations (Agresti, 1996), we performed the asymptotic Fisher’s Exact Test to test for the independence between types of explanations and the actors. Results showed that there were no statistically reliable differences between the types of explanations children provided for each actor.

**Test trial.** For Actor 1, 92% of the responses were coded as individual preference; the remaining responses were coded as non-explanatory. For Actor 2, 91% of the responses were coded as new preference, 2% were coded as individual preference, and the remaining 7% of the responses were coded as non-explanatory. A Fisher’s Exact Test indicates that children provided significantly more individual preference explanations for Actor 1 than for Actor 2, \( p < .001. \)
New evidence trial. In the new evidence trial, the participants again gave only two types of responses for the consistent event (Actor 1). They either indicated that Actor 1 maintained her individual preference throughout the trials (93%) or they gave a non-explanatory response (7%). The most common explanation given for the inconsistent event (Actor 2) was a new goal explanation (83%), in which the child indicated that Actor 2 liked cookies and not apples (e.g., “She likes cookies.”). The only other response provided by participants was non-explanatory (17%). The Chi-square analysis revealed that a significantly higher proportion of children provided individual preference explanations for the consistent event (Actor 1) than for the event that had appeared inconsistent in the test trial (Actor 2), \( \chi^2 = 108.5, (1, N = 60), p < .001, \) Cramer’s \( V = .94. \)

Revision of explanations

The content of children’s explanations for Actor 1 (who behaved consistently across trials) did not change. Children provided predominantly individual preference explanations for the confirmation (98%), test (92%), and new evidence trials (93%). However, the content of children’s explanations for Actor 2 (who behaved consistently in the confirmation trial and inconsistently in the test trial) changed dramatically across trials. Although children provided predominantly individual preference explanations for Actor 2 in the confirmation trial (93%), they revised their explanations in the test trial by providing new preference explanations (91%), and again revised their explanations in the new evidence trial by providing new goal explanations (83%). Results showed that 85% of participants changed their explanation for the inconsistent event from individual preference in the confirmation trial to new preference in the test trial and 77% of participants changed their explanations from new preference in the test trial
to new goal in the new evidence trial. Binomial tests confirmed that both explanatory revisions between trials were above chance, $ps < .001$.

**Discussion**

The results from Study 1 provide converging evidence that inconsistency serves as a powerful explanatory trigger in young children, extending previous work by Legare et al. (2010) in the domain of naïve physics. This research also demonstrated that children incorporated new evidence into their overall explanation of the inconsistent event (Actor 2), revising their explanations for inconsistent outcomes across trials based on new evidence. Notably, however, the content of children’s explanations for Actor 1 (who behaved consistently across trials) did not change. Children provided predominantly individual preference explanations for the confirmation (98%), test (92%), and new evidence trials (93%). The fact that this pattern of responses is similar across all three trials (confirmation, test, and new evidence) indicates that without additional information, children are not motivated to change their explanations. Taken together, these results indicate that children are particularly sensitive to novel information and will flexibly incorporate it into their explanations of inconsistent events.

The design of Study 1 enabled us to investigate inconsistency as a causal reasoning mechanism; however, there are several limitations and open questions. Notably, Actor 2 in Study 1 reached for an apple after stating she did not like apples. It is possible that children were more likely to explain Actor 2 first because she demonstrated a novel action, not because she was acting in an inconsistent manner. In Study 2, we sought to examine whether children were more likely to first explain inconsistent over consistent outcomes rather than simply explaining action (i.e., reaching for an apple) versus inaction (i.e., crossing arms). Secondly, results from the confirmation trial showed that a positive preference (e.g., liking rather than disliking apples)
served as a more dominant explanatory trigger than a negative preference when no inconsistency with the actors’ preferences had yet been presented. One possibility is that expressing a preference is more salient than expressing distaste and thus children may have been more likely to explain the behavior of the actor who was reaching for the apple (Actor 1) than the actor who didn’t participate in any goal-directed action and only crossed her arms (Actor 2). Another possibility is that in Study 1, the actor who stated she liked apples (Actor 1) was described first (on the left side of the screen) and it is possible that children were explaining what had been presented with first. In Study 2, we addressed these concerns in addition to examining how new evidence from another domain (naïve biology) would influence children’s explanations.

**Study 2**

Study 2 extends upon Study 1 by including another kind of information (contamination) in the new evidence trial. Children have complex beliefs about biological processes at very young ages (Inagaki & Hatano, 2002; Wellman & Gelman, 1992; Wellman et al., 1997). Even 3-year-olds recognize biological causes (Kalish, 1996a) and can explicitly use appropriate language to articulate this understanding (Wellman et al., 1997). Children are also very interested in biological phenomena and provide explanations that refer to non-obvious properties and entities (Au, Sidle, & Rollins, 1993; Legare et al., 2009). For example, preschool children recognize that germs or contamination are responsible for the transmission of contagious illnesses (Inagaki & Hatano, 2002; Kalish, 1996b; Springer & Ruckel, 1992), although this understanding appears to be at a skeletal framework level (Au, Romo, & DeWitt, 1999; Raman & Winer, 2002, 2004; Solomon & Cassimatis, 1999).

As in Study 1, we provided participants with information about the stated preferences for two actors (i.e., liking and disliking oranges). The confirmation trial was identical to Study 1.
The test trial was also identical with the exception of the kind of action the actors engaged in (i.e., both actors refrained from reaching for an orange). Therefore, Actor 1 (who disliked oranges) engaged in an action consistent with her stated preference while Actor 2 (who liked oranges) engaged in an action inconsistent with her stated preference. Finally, as in Study 1, in the new evidence trial the action sequence from the previous trial continued but this time a previously hidden bug was revealed on the orange Actor 2 had refrained from reaching for. Thus, participants had access to new information or an alternative explanation for the inconsistent outcome. We predicted that children would flexibly revise their explanations for inconsistent outcomes by incorporating evidence across domains, switching from naïve psychology explanations (preferences) to naïve biology explanations (contamination) in the new evidence trial.

**Method**

**Participants**

Fourteen 3-year-olds ($M = 3.6; \text{ range } = 3.3-3.9$), sixteen 4-year-olds ($M = 4.3; \text{ range } = 4.0-4.9$), fifteen 5-year-olds ($M = 5.2; \text{ range } = 5.0-5.7$), and fifteen 6-year-olds ($M = 6.3; \text{ range } = 6.0-6.7$) were recruited from a Southwest U.S. university city. Participants were primarily Euro-American and from middle-class families. Thirty-one boys and 29 girls participated in the study.

**Materials**

Video stimuli were created for each of the four segments in the experiment. All videos depicted two female actors wearing differently colored t-shirts (i.e., Actor 1 wore an orange shirt and Actor 2 wore a green shirt). Videos were presented on a 15” laptop screen.

**Procedure**
The procedure for Study 2 was identical to Study 1 with the exception of modifications to the video content. The sessions consisted of a training task and three experimental trials: a confirmation trial, a test trial, and a new evidence trial (Table 2). Following each question, children were given an opportunity to follow-up their response (e.g., can you tell me anymore about that?) If children failed to provide a response, the experimenter restated the question.

**Training trial.** Each child was first presented with a video clip of the two actors stating their preferences about oranges. Actor 1 stated her preference first by saying, “I don’t like oranges. Oranges are not my favorite food. I don’t like to eat oranges.” Actor 2 stated her preference second by saying, “I like oranges. Oranges are my favorite food. I like to eat oranges.” The video was then paused and the experimenter asked the child about the individual preferences of the actors as in Study 1 to test for comprehension. If the child answered these questions correctly, the experimenter continued with the rest of the procedure. If the child answered incorrectly, the video was replayed and the questions were repeated. If the child answered incorrectly a second time, the study was terminated.

**Confirmation trial.** Next, the child was presented with a video in which the actors were seated behind a table. On the table was a plate with two oranges. The actors simultaneously behaved in a manner that was consistent with their previously stated preferences. Actor 1 (who had stated a dislike for oranges) crossed her arms, whereas Actor 2 (who had stated a preference for oranges) reached toward the oranges. The video was then paused, and the participant was asked a series of questions exactly the same as those in the confirmation trial of Study 1. As in Study 1, we predicted that children would show no preference for which actor to explain first.

**Test trial.** Following the confirmation trial, the child participated in the test trial. Prior to the start of the video, the child was told that she would see the same people as in the previous
video, but that this time they would have two new oranges. In this video, Actor 1 (who disliked oranges) behaved in a manner consistent with her stated preference (i.e., crossing her arms) and Actor 2 (who liked oranges) behaved in a manner that was inconsistent with her stated preference (i.e., she too crossed her arms). Both actors crossed their arms simultaneously. The video was paused and the experimenter asked the same questions as in the test trial of Study 1. Again, our predictions were the same as they were for Study 1, that children would be more likely to explain the inconsistent event first.

**New evidence trial.** Prior to the start of the new evidence trial, the experimenter told the child, “Let’s keep watching!” in order to communicate that this video was a continuation of the previous video. The video was continued from where it had been paused (with both actors’ arms crossed over their chests), and Actor 1 continued to act in a manner consistent with her stated preference by continuing to cross her arms. The continuation of the video showed a bug that appeared to be climbing over the orange closest to Actor 2 (who liked oranges and behaved inconsistently in the test trial). Both actors remained with their arms crossed over their chests for the duration of the video while the bug appeared to crawl over Actor 2’s orange. This new information, that Actor 2 had not reached for an orange because a bug had contaminated it, provided an alternative explanation for Actor 2’s behavior. As in Study 1 and with all previous trials, the participant was asked the explanatory prompt and follow-up questions if necessary. Our predictions for Study 2’s new evidence trial were the same as for Study 1, that children would revise their explanation of Actor 2’s behavior.

Table 2

*Study 2 design*

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<th>Actor 1</th>
<th>Actor 2</th>
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</table>
Coding

The entire session was videotaped and transcribed verbatim. For each trial, children’s responses were coded for which actor’s behavior was explained first and for the content of the explanations. Content codes varied by trial, with later trials allowing for more variable explanations.

**Confirmation trial.** Responses were categorized exactly as they were in Study 1 as either *individual preference* or *non-explanatory*.

**Test trial.** As in Study 1 and in the confirmation trial, responses for the consistent event were categorized as *individual preference* or *non-explanatory*. Responses for the inconsistent event were coded as *individual preference*, *non-explanatory* or *new preference*. *New preference* explanations indicated that the actor had changed her previously stated preference (e.g., “She changed her mind about oranges”).

**New evidence trial.** As in previous trials, responses for the consistent event were coded as *individual preference* or *non-explanatory*. Interestingly, several children providing individual preference explanations referred to contamination as a possible reason for Actor 1’s preference.

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<thead>
<tr>
<th>Statement of Preference</th>
<th>Does not like oranges</th>
<th>Likes oranges</th>
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</thead>
<tbody>
<tr>
<td><strong>Confirmation Trial</strong></td>
<td>Does not reach for an orange</td>
<td>Reaches for an orange</td>
</tr>
<tr>
<td><strong>Test Trial</strong></td>
<td>Does not reach for an orange (consistent)</td>
<td>Does not reach for an orange (inconsistent)</td>
</tr>
<tr>
<td><strong>New Evidence Trial</strong></td>
<td>Does not reach for an orange (no new evidence)</td>
<td>Does not reach for a bug that appears to climb over an orange (new evidence)</td>
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</table>
(e.g., “Maybe she doesn’t like oranges because she thinks the dirty bug has been on it.”).

Responses for the inconsistent event were coded as individual preference, non-explanatory, new preference, or new goal. New goal explanations stated that Actor 2 had not revised her previous preference (a preference for oranges), but instead referred to biological contamination (e.g., “Because a bug might make germs on it. Bugs are really dirty, bugs have a real lot of germs on them,” and “Because the bug is really nasty and dirty.”).

To examine children’s ability to revise explanations, we examined the consistency of the aforementioned explanatory categories between trials. If no change occurred across trials, children were assigned a score of 0; if children provided a different explanation from one trial to the next, they were assigned a score of 1. For example, if a child provided an individual preference explanation in the confirmation trial and a new preference explanation in the test trial, she was given a score of 1. There were a total of three trials (two changes) so scores ranged from 0-2.

Inter-rater reliability was established using a randomly selected sample of 25% of the data. Reliability was calculated for whether or not the participants first explained Actor 1 or Actor 2 (94% agreement) as well as the type of explanation (91% agreement). All of the Kappas for this coding fall within or near perfect (.81 and above) levels (Landis & Koch, 1977).

**Results**

The analyses for Study 2 were similar to the ones performed in Study 1. Again, the results confirmed our initial hypotheses: a higher proportion of children first explained inconsistent than consistent actions and were able to revise their explanations in response to new information about the inconsistent event. Next we present data on which outcome children explained first, the content of their explanations, and changes in their explanations across trials.
All analyses were first run with age as a factor, and, when no effects of age were found, this factor was removed from subsequent analyses.

**First explanation**

As in Study 1, to assess whether an inconsistent event served as an explanatory trigger, we compared the proportion of children who provided an explanation for the inconsistent action first to the proportion of children who provided an explanation for the consistent action first.

In the confirmation trial, which was designed to ensure that children could explain the actions of the two actors when they were both acting consistently, a Chi-square test revealed that significantly more children explained the actor who liked oranges (Actor 2, 63%) first as compared to the actor who disliked oranges (Actor 1, 10%), \( \chi^2 = 38.4, (1, N = 60), p < .001, \) Cramer’s V = .79. The remaining children (37%) referred to both actors simultaneously.

Similarly, in the test trial analysis revealed that reliably more children explained the inconsistent event first (Actor 2, 17%) as compared to the consistent event (Actor 1, 5%), \( \chi^2 = 55.9, (1, N = 60), p < .001, \) Cramer’s V = .67. A large proportion of children referred to both outcomes in their first explanation (78%). For example, “they both don’t like oranges now.”

Similarly, in the new evidence trial, children were more likely to first explain the inconsistent event (Actor 2, 43%) as compared to the consistent event (Actor 1, 10%), \( \chi^2 = 14.8, (1, N = 60), p < .001, \) Cramer’s V = .34. The remaining children (47%) referred to both actors simultaneously.

**Content of explanations**

**Confirmation trial.** For Actor 1 (who disliked oranges), 97% of the explanations were coded as individual preference, the remaining 3% of responses were coded as non-explanatory. For Actor 2 (who liked oranges), 97% of the explanations were coded as individual preference,
the remaining 3% of the responses were coded as non-explanatory. There were no significant
differences between the types of explanations provided by individual preference, $\chi^2 = .25$, (1, $N$
= 60), ns.

**Test trial.** For Actor 1, 97% of the explanations were coded as individual preference
(e.g., she dislikes oranges); the remaining responses were coded as non-explanatory. For Actor
2, 92% of the explanations were coded as new preference (e.g., “She doesn’t like oranges
anymore.”) and the remaining 8% of the responses were coded as non-explanatory. A Fisher’s
Exact Test indicated that participants provided significantly more individual preference
explanations for Actor 1 than for Actor 2, $p < .001$.

**New evidence trial.** In the new evidence trial, the participants once again gave only two
types of responses for Actor 1 (who dislikes oranges and behaved consistently). They either
indicated that the actor maintained her individual preference throughout the trials (95%) or they
gave a non-explanatory response (5%). A small portion of the individual preference explanations
referred to contamination as a potential reason for the actor’s dislike of oranges (14%; e.g., “She
didn’t like the bug on the orange either, she didn’t want to eat the orange if the bug may be
there.”). The most common explanation given for the inconsistent event was a new goal
explanation, where the child indicated that Actor 2 had avoided the orange because it had been
contaminated (e.g., “The bug made the orange yucky;” 78%). The only other responses given by
the participants were new preference explanations, a reiteration of the explanations provided for
the inconsistent outcome in the test trial (21%). A Fisher’s Exact Test revealed that children
were much more likely to provide individual preference explanations for Actor 1 than for Actor
2, $p < .001$.

**Revision of explanations**
The content of children’s explanations for Actor 1 (who behaved consistently across trials) did not change across trials. Children provided predominantly individual preference explanations for the confirmation (97%), test (97%), and new evidence trials (95%). However, the content of children’s explanations for Actor 2 (who behaved consistently in the confirmation trial and inconsistently in the test trial) changed dramatically across trials. Although children provided predominantly individual preference explanations for Actor 2 in the confirmation trial (97%), they revised their explanations in the test trial by providing new preference explanations (92%), and again in the new evidence trial by providing new goal explanations (78%). Results showed that 90% of participants changed their explanation for the inconsistent event from individual preference in the confirmation trial to new preference in the test trial and 71% of participants changed their explanations from new preference in the test trial to new goal in the new evidence trial. Binomial tests confirmed that both explanatory revisions between trials were above chance, $ps < .001$.

**Discussion**

The results of Study 2 replicate the results of Study 1, demonstrating that inconsistent events serve as a more powerful explanatory trigger than consistent events. Children were more likely to first explain the behavior of Actor 2 (who acted inconsistently with her stated preference) than of Actor 1 (who acted consistently with her stated preference). Not only did children explain the inconsistent event first in the test trial, they also readily incorporated new evidence about potential contamination into their explanations for the inconsistent outcome in the new evidence trial. Children revised their preference-based, psychological explanations in the test trial to incorporate new, cross-domain information about potential contamination in the new evidence trial.
Study 2 also addressed methodological concerns with Study 1. In Study 1, the actor with a positive preference was presented first and was on the left side of the screen. In Study 2, the actor with a positive preference was presented second and was on the right side of the screen. In the confirmation trial in Study 2 children were more likely to first explain the actor who expressed a positive preference, even though information about this actor was presented last. Additionally, although the inconsistent event in Study 2 involved inhibiting a previously modeled behavior (i.e., crossing arms after stating she liked oranges) rather than engaging in a new behavior in Study 1 (i.e., appearing to reach for an apple after stating she did not like apples), children explained the inconsistent event first in the test trial in both studies.

**General Discussion**

There is mounting evidence that children’s explanations facilitate causal knowledge acquisition (Wellman, 2011) and that explaining inconsistent outcomes guides hypothesis-testing behavior (Legare, 2012; 2014; Stahl & Feigenson, 2015). The current studies contribute to our understanding of the relationship between evidence and explanation and demonstrate children's ease in revising their explanations to accommodate new information. Measures of explanation revision demonstrate that children are not tied to their previous explanations, but think flexibly and appropriately to accommodate new evidence.

If explanation plays a role in acquiring new information and constructing new understanding, then learners should explain the observations that have the greatest potential to teach them something new, namely, those that are inconsistent with respect to their prior knowledge and thus motivate further information seeking. Biases to explain inconsistent information could aid in learning by focusing children on events that challenge current causal
knowledge and provoke additional, amended causal reasoning by increasing awareness of uncertainty and the potential for multiple interpretations of the same information (Legare, 2014).

The current studies provide converging support for the hypothesis that inconsistent outcomes trigger explanation in early childhood. Data from both studies indicate that children are more likely to first explain inconsistent than consistent psychological outcomes, replicating work by Legare and colleagues in the physical domain (Legare, et al., 2010). Notably, however, many children referred to both outcomes in their first explanation, particularly in Study 2. This is likely due to the contrastive nature of our experimental design (i.e., outcomes were presented to children simultaneously).

The data from both studies also demonstrate that the types of explanations that children provide are driven by the type of information they receive. In Study 1, the content of children’s explanations for Actor 2 (who behaved consistently in the confirmation trial and inconsistently in the test trial) changed dramatically across trials. Although children provided predominantly individual preference explanations for Actor 2 in the confirmation trial, they revised their explanations in the test trial by providing new preference explanations, and again revised their explanations in the new evidence trial by providing new goal (i.e., additional preference) explanations. Results showed that 85% of participants changed their explanation for the inconsistent event from individual preference in the confirmation trial to new preference in the test trial and 77% of participants changed their explanations from new preference in the test trial to new goal in the new evidence trial.

In Study 2, the content of children’s explanations for Actor 2 (who behaved consistently in the confirmation trial and inconsistently in the test trial) changed dramatically across trials. Although children provided predominantly individual preference explanations for Actor 2 in the
confirmation trial, they revised their explanations in the test trial by providing new preference explanations, and again in the new evidence trial by providing new goal explanations. Results showed that 90% of participants changed their explanation for the inconsistent event from individual preference in the confirmation trial to new preference in the test trial and 71% of participants changed their explanations from new preference in the test trial to new goal (avoiding contamination) in the new evidence trial. These data demonstrate that children revise their explanations for inconsistent outcomes to incorporate new information within the psychological domain (Study 1) and between the psychological and biological domains (Study 2).

There is convergent evidence that inconsistent or surprising outcomes influence children’s predictions and explanations of actions. For example, in previous work by Goodman and colleagues, approximately 25% of preschoolers changed their prediction on a false belief test after being confronted with a surprising outcome on a previous trial. Children also relied on new preference explanations to account for the surprising outcome, consistent with the results of the current studies (Goodman et al., 2006). However, the current studies provide a more direct test of children’s ability to revise explanations by directly contrasting consistent and inconsistent actions in the same trials, and by introducing new evidence after the inconsistent outcome. The children’s ease in revising their explanations to accommodate the new information shows they are not tied to new preference explanations, but are thinking flexibly and appropriately to incorporate new information.

Why do children so readily revise their belief that the inconsistent actor changed her desire when presented with new evidence? When an agent acts in ways contrary to her stated preferences or goals, the situation is genuinely perplexing. Claiming the agent changed her desire
works to explain why someone who dislikes apples would reach for one and why someone who likes oranges would refrain, in the absence of any clear reason the ineffectual actions. The introduction of new evidence (i.e., the cookies or bug), however, allows the children to generate much more specific explanations. Adults show a marked preference for explanations that account for a small number of potential effects (a narrow latent scope) rather than explanations that could apply in a larger number of situations (Johnson, Rajeev-Kumar, & Keil, 2014; Khemlani, Sussman, & Oppenheimer, 2011). Perhaps children are exhibiting the same bias towards narrow latent scope explanations.

If explanation is a cognitive mechanism for acquiring knowledge and constructing new understanding, children should not only be motivated to seek out and construct explanations for the complex world around them; they should also flexibly revise explanations in response to new information. Data from two studies demonstrate that children readily attend to inconsistent outcomes and flexibly accommodate different kinds of information when revising their explanations for inconsistent outcomes. Encouraging children to explain inconsistent information confronts children with the evidence most likely to foster explanation revision, and provides insight into the relationship between explanation and learning.
References


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