Journal of Experimental Child Psychology 183 (2019) 172–188

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Using data to solve problems: Children reason flexibly in response to different kinds of evidence

Justin T.A. Busch *, Cristine H. Legare

Department of Psychology, The University of Texas at Austin, Austin, TX 78712, USA

A R T I C L E   I N F O

Article history:
Received 19 June 2018
Revised 5 January 2019

Keywords:
Cognitive development
Transitive reasoning
Explanation
Inquiry
Problem solving
Evidence evaluation

A B S T R A C T

This study examined children's (5- to 9-year-olds, $N = 363$) abilities to use information seeking and explanation to solve problems using conclusive or inconclusive (i.e., consistent, inconsistent, or ambiguous) evidence. Results demonstrated that inconsistent and ambiguous evidence, not consistent evidence, motivate more requests for information than conclusive evidence. In addition, children's explanations were flexible in response to evidence; explanations based on transitive inference were more likely to be associated with an accurate conclusion than other explanation types. Children's requests for additional information in response to inconclusive evidence increased with age, as did their problem-solving accuracy. The data demonstrate that children's capacity to use information seeking and explanation develop in tandem as tools for problem solving.

Introduction

Gaining active and intentional control over problem solving is a fundamental cognitive developmental task (Bjorklund, Dukes, & Brown, 2009; Coyle & Bjorklund, 1997; Harnishfeger & Bjorklund, 1990; Schwenck, Bjorklund, & Schneider, 2009; Shrager & Siegler, 1998; Siegler, 2005). Yet little is known about how different kinds of information influence children's ability to seek out and interpret evidence to solve problems. Examining how children engage in problem solving in response to

* Corresponding author.
E-mail address: justin.ta.busch@utexas.edu (J.T.A. Busch).

https://doi.org/10.1016/j.jecp.2019.01.007

different types of evidence provides insight into understanding the complex interplay among information seeking, explanation, and reasoning.

Effective problem solving is a complex cognitive process. First, children must evaluate different kinds of information to determine whether the evidence they have is sufficient to solve a problem. If they conclude that they lack sufficient information to do so effectively, they must seek out additional, diagnostic information. They may also need to revise their beliefs about the problem in response to new information. Finally, they must integrate and reason about evidence to solve the problem. In the current study, we examined the effects of different kinds of evidence on children's ability to use information seeking and explanation to solve problems. Before describing the experimental design, we discuss prior research on information seeking and reasoning about different kinds of evidence, the role of explanation in facilitating problem solving, and the development of problem solving and transitive inference in childhood.

Information seeking and reasoning about evidence

What kinds of evidence motivate information seeking in children? Children readily make use of covariation information, statistical regularities, and causal relationships to understand and predict outcomes, frequently from limited available input (Kushnir & Gopnik, 2007; Schulz & Gopnik, 2004). For example, when children are shown evidence of variation and covariation, they use this information in their causal judgments (Gopnik, Sobel, Schulz, & Glymour, 2001). A cognitive model of the world based on a framework of anticipatory regularities would equip children to rapidly form expectations contingent on prior beliefs or knowledge. Because children readily form expectations for observed regularities based on prior knowledge (even when sparse), children may be highly motivated to attend to irregular or discordant information (Legare, Gelman, & Wellman, 2010). Information that is inconsistent with how they expect things to happen could be especially informative because it indicates that their prior knowledge about a relationship or outcome was incomplete or inaccurate. Children may be particularly attentive to, and more likely to attempt to understand, disconfirmatory outcomes.

Inconsistency with prior knowledge may increase children's motivation to seek out evidence by disconfirming their current state of knowledge (Legare, 2014). When children are faced with different kinds of inconclusive evidence (i.e., evidence that is inconsistent with prior knowledge or ambiguous), it may prompt them to consider multiple potential alternative explanations, whereas other types of evidence that are equally inconclusive (i.e., evidence that is consistent with prior knowledge) might not. The proposal that inconsistent, problematic, or surprising outcomes play an important role in reasoning appears across multiple literatures—philosophy of science (Hempel, 1965), social psychology (Hilton, 1995), educational research (Chi, Bassok, Lewis, Reimann, & Glaser, 1989), and infancy research (Baillargeon, 2002). Recent research has demonstrated that information that is inconsistent with children's prior knowledge motivates information seeking during infancy (Stahl & Feigenson, 2015) and early childhood (Legare, 2012; Legare & Gelman, 2014; Legare et al., 2010; Legare, Schult, Impola, & Souza, 2016). For example, infants show greater exploration of objects that violate their expectations of the physical world such as an object passing through another solid object or an object being suspended in the air without support (Stahl & Feigenson, 2015). Similarly, preschool children who were trained on the causal rules of a novel machine are more likely to generate explanations for events that violate their understanding of causal relations (Legare et al., 2010).

To effectively seek out evidence in the service of problem solving, children must be sensitive to gaps in their own knowledge. Children are sensitive to these limitations; they selectively explore situations where the evidence is incongruent with their favored hypothesis or the evidence is equally consistent with more than one hypothesis (Schulz, 2012). Children are also sensitive to the quality and completeness of the information they receive (Gweon, Pelton, Konopka, & Schulz, 2014), which in turn may influence their level of curiosity and exploration (Bonawitz et al., 2011). For example, research by Schulz and Bonawitz (2007) showed that preschoolers preferentially explore causally confounded objects over causally unambiguous objects.

Not only do children engage in broad exploration in contexts where they have limited information, they also are adept at using questions to satisfy their curiosity and accumulate additional evidence

(Chouinard, 2007; Courage, 1989; Legare, Mills, Souza, Plummer, & Yasskin, 2013). Research by Legare et al. (2013) found that the number of constraint-seeking questions, or questions that were appropriately worded to obtain the necessary information, predicted children's accuracy on a problem-solving task. Children also ask relevant questions and adapt the types of questions they ask to increase their efficiency in acquiring new evidence (Legare et al., 2013; Ruggeri & Lombrozo, 2015; Ruggeri, Lombrozo, Griffiths, & Xu, 2016; Ruggeri, Sim, & Xu, 2017), a skill that improves over the course of development (Chouinard, 2007; Mills, Legare, Bills, & Mejias, 2010). Young children are dissatisfied with nonexplanatory responses to their causal questions. They prefer to question informants who provide noncircular explanations and will selectively direct their questions to a knowledgeable informant, which improves their ability to successfully complete a problem-solving task (Corriveau & Kurkul, 2014; Frazier, Gelman, & Wellman, 2009; Mills, Legare, Grant, & Landrum, 2011). This suggests that children's ability to not only seek information but also seek diagnostic evidence from a knowledgeable informant is a critical skill in the development of problem solving.

Role of explanation in problem solving

Inconsistent outcomes do more than motivate information seeking; they also motivate children to generate explanations (Legare, 2014). For example, there is evidence that children are more likely to explain inconsistent outcomes than consistent outcomes (Legare, 2012; Legare & Gelman, 2014; Legare et al., 2010, 2016). It is unclear, however, what it is about inconsistency that motivates children to explain. One possibility is that inconsistent evidence is inconclusive and, thus, children are motivated to explain in order to resolve uncertainty (Foster & Keane, 2015). However, uncertainty is not unique to inconsistent evidence. Consistent evidence can also be inconclusive (Pearl, 2009). For example, parents may observe that their child has a runny nose around the same time every September when their child goes back to school. They might attribute this symptom to their child's increased exposure to fellow students who carry illness-causing viruses. The evidence for this hypothesis is consistent; the symptoms coincide with going back to school each September. Yet the evidence is also inconclusive because there are alternative explanations. For instance, it is possible that their child's symptoms are the result of ragweed allergies that peak during the fall. Thus, even when the evidence is consistent, it can still be inconclusive and require additional information to reach an accurate conclusion.

Engaging in explanation provides children with the opportunity to accommodate and reconcile inconsistent or ambiguous information and to generate new hypotheses regarding events that seem to disconfirm their prior knowledge (Legare, 2014; Legare et al., 2010; Sobel & Legare, 2014). A bias to explain inconsistent information could scaffold the learning process by directing children's attention to events that challenge their current understanding and prompt them to explore alternative hypotheses they might not have considered (Bonawitz, Fischer, & Schulz, 2012; Legare, 2012; Stahl & Feigenson, 2015). Inconsistent evidence may provide children with the opportunity to explore new hypotheses for events that, at first, disconfirm current beliefs (Walker, Williams, Lombrozo, & Gopnik, 2012). The kind of explanation children provide for inconsistent outcomes informs the kind of exploratory behavior they engage in and the extent to which they modify and generate new hypotheses (Legare, 2012). The active process of searching for an explanation may also lead to knowledge acquisition (Legare & Lombrozo, 2014; Legare, Sobel, & Callanan, 2017; Walker, Lombrozo, Legare, & Gopnik, 2014; Wilkenfeld & Lombrozo, 2015). For example, children who were prompted to explain the solutions to a task to themselves or to their mothers showed greater problem-solving accuracy at posttest than children who simply repeated the solutions to the problems (Rittle-Johnson, Saylor, & Swygert, 2008).

Using information to solve a problem requires recognizing that the information is relevant to the problem at hand (Koslowski, Marasia, Chelenza, & Dublin, 2008). Explanation may play an integral role in identifying information as evidence; adults are more likely to understand that the information they possess can be used as evidence if they have an explanation that incorporates the information into a single explanatory framework. If generating explanations facilitates the identification of information as relevant evidence, we should predict that the interaction of reasoning about evidence and explanation would be integral to problem solving (Willard et al., in press).

Development of problem solving

Solving a problem requires attending to and encoding evidence, effective evaluation of the evidence, and mapping of the evidence onto the problem (Fay & Klahr, 1996). This process presents a significant challenge for both children and adults. In tasks with multiple causal processes that can influence an outcome, children and adults often manipulate too many variables simultaneously to sufficiently test their hypothesis (Schauble, 1996). Children and adults also struggle to articulate what type of evidence would be predicted by their causal theories (Kuhn, Amsel, & O'Loughlin, 1988). This suggests that when children are required to explain their reasoning about evidence, or to design interventions to solve a problem, they encounter a great deal of difficulty. In contrast, other research shows that children can effectively select and design interventions to disambiguate confounded variables (Cook, Goodman, & Schulz, 2011). For example, a study that examined preschoolers' understanding of shadows found that when evidence is inconsistent with children's naïve theories, children use unconfounded experiments to reconcile this conflict (van Schijndel, Visser, van Bers, & Raijmakers, 2015). However, children engage in these processes of intervention only when the evidence is ambiguous or conflicting. This suggests that children's ability to use evidence in problem solving may be influenced by the type of evidence they have at their disposal. In much the same way that information seeking and explanation generation are triggered by specific types of evidence, the way that children use evidence to solve problems may be closely tied to the type of evidence they observe.

Solving problems using conclusive evidence also requires complex reasoning. For example, transitive inference is a form of reasoning in which a conclusion can be drawn about the relation between two items (e.g., tomas are heavier than blickets) even when this evidence is not presented directly. Instead, the evidence is presented indirectly about the two items and a mutual item (e.g., tomas are heavier than widgets and widgets are heavier than blickets). The ability to draw a conclusion through transitive inference appears to be early developing (Gazes, Hampton, & Lourenco, 2017; Mou, Province, & Luo, 2014). In looking time studies, 16-month-old infants have been shown to make transitive inferences of the type if A > B and B > C, then A > C, and children older than 5 years are highly successful at transitive inference tasks considering two binary relations, as in the example presented above (Halford, 1984). Children are also more confident in knowledge they have attained through transitive inference than they are in knowledge based off of a guess (Pillow, 2002). Furthermore, many nonhuman animals appear to be capable of transitive inference, including rodents, crows, pigeons, and monkeys (Vasconcelos, 2008). In the current study, we used the early-developing ability to engage in transitive inference to examine how children reason about conclusive evidence.

The current study

Our objective was to compare how different types of evidence would affect information seeking, explanation, and problem-solving accuracy in children. We presented children with four different types of information about an actor's food preference that was either inconclusive (i.e., consistent, inconsistent, or ambiguous) or conclusive (i.e., transitive) and then asked them to determine the actor's favorite fruit from three different options (Table 1). The task depicted the reaching action of

Table 1
Evidence condition at Trial 1 and evidence options available at Trial 2.

		Consistent	Inconsistent	Ambiguous	Conclusive
Trial 1	Video 1	Apple–<u>Banana</u>	Apple–<u>Banana</u>	Apple–<u>Banana</u>	Apple–<u>Banana</u>
	Video 2	<u>Banana</u>–Apple	<u>Apple</u>–Banana	<u>Orange</u>–Apple	<u>Orange</u>–Banana
Trial 2	New vs. repeat	Repeat:	Repeat:	Repeat:	Repeat:
		Apple–<u>Banana</u>	Apple–<u>Banana</u>	Apple–<u>Orange</u>	Banana–<u>Orange</u>
		New:	New:	New:	New:
		Banana–<u>Orange</u>	Apple–<u>Orange</u>	Banana–<u>Orange</u>	Apple–<u>Orange</u>

Note. The fruit selected by the actor is underlined in each case.

an actor as evidence for preference. After observing the evidence, children were given the opportunity to seek additional information or draw a conclusion about the actor's favorite fruit (Trial 1). Children who requested additional information continued on to Trial 2, where they were again given the option of seeking more information or drawing a conclusion. At both Trial 1 and Trial 2, we examined children's propensity to seek out additional information, the kinds of explanations children generated, and how the kind of information children received and the explanations they generated were associated with their accuracy on the task. The task was completed when children made an accurate guess.

First, we examined children's information seeking by condition and age. We assessed whether children thought they could solve the task with the information they had or needed more information. Based on past research (Cook et al., 2011; Legare & Gelman, 2014), we predicted that information that was inconsistent or ambiguous would motivate more information seeking after Trial 1 compared with evidence that was conclusive (transitive condition). Conversely, we predicted that consistent information, while still inconclusive, would not motivate information seeking compared with conclusive evidence. We also predicted that information seeking would increase with age. Previous research indicates that 6- and 7-year-olds are sensitive to omissions of information (Gweon et al., 2014) and will discriminate between informants who omit information and those who do not. In contrast, 4- and 5-year-olds show no preference for an informant who provides complete information (Einav & Robinson, 2010) and overestimate their own level of knowledge (Beck & Robinson, 2001; Kloo, Rohwer, & Perner, 2017). This suggests that it is not until around 6 years of age children can evaluate the sufficiency of evidence.

Next, we examined how children use explanation in response to evidence. We coded children's explanations to examine the role that evidence plays in the type of explanations children generate and to examine how explanation functions as a tool for problem solving. We define *explanation* broadly as any utterance that can provide an answer to a *how* or *why* question (Wellman, 2011). Children provided an explanation each time they made a guess about the actor's favorite fruit. We predicted that children's explanations would differ based on the type of information they received (Legare & Gelman, 2014; Legare et al., 2010). For example, we predicted that children in the transitive condition would provide more explanations that appealed to explicit inferential reasoning and that children in the consistent condition would provide more explanations about the raw frequency of the results they had observed.

Finally, we examined children's problem-solving accuracy by condition and age. We predicted that children who initially viewed consistent evidence would be less accurate than children in the inconsistent, ambiguous, and transitive conditions, perhaps due to an insufficient adjustment of existing knowledge, or anchoring (Tversky & Kahneman, 1974). Similar to studies with adults, confirmation bias may also inhibit children's ability to accurately complete the task by causing children to discount evidence that does not confirm the consistent evidence they already witnessed (Klahr & Dunbar, 1988). We predicted that children who observed transitive evidence would be more accurate than children who observed all other types of evidence. Across conditions, we predicted that children's problem-solving accuracy would increase with age based on previous research showing that children are influenced by their prior beliefs when drawing conclusions about evidence (Amsel & Brock, 1996) and that reasoning about evidence develops incrementally. For example, it is not until middle childhood that the abilities to evaluate ambiguous evidence and discriminate between conclusive and inconclusive experimentation emerge (Piekny & Maehler, 2012).

Method

Participants

In total, 100 5-year-olds, 76 6-year-olds, 59 7-year-olds, 69 8-year-olds, and 59 9-year-olds ($N = 363$) were recruited from a southwestern U.S. city. Participants were primarily Euro-American and from middle-class families. Participants were recruited from a local children's museum, from an after-school program, or from the birth record database maintained by the university. In total, 183 boys and 179 girls participated in the study (1 participant did not report his or her sex).

Materials

Participants were video- and audio-recorded. The study stimuli were presented to the participants on a laptop computer placed directly in front of them. The stimuli videos depicted a live-action adult woman sitting at a table in front of a neutral background. The only additional materials used during the study were three pieces of artificial fruit: an apple, an orange, and a banana. The artificial fruit was used to make the three different target items salient to the children.

Procedure

Participants were randomly assigned to one of four between-participants conditions; three conditions presented inconclusive evidence (consistent, inconsistent, or ambiguous) and one condition presented conclusive evidence (transitive). Each participant was tested individually in a 15-min session. Across conditions, the experimenter first explained to the participants that their goal would be to figure out the favorite fruit of an actor. The experimenter then stated that the actor's favorite fruit could be an apple, an orange, or a banana and that to determine which of the three options was the actor's favorite, the children would need to use information about the actor's choices.

The information consisted of videos of the actor seated at a table with two pieces of fruit (two of the three possible options) placed on the table before her. In each video, the actor reached out to pick up one of the pieces of fruit. The videos ended just prior to the actor's hand making contact with a piece of fruit. The hand the actor reached with was held constant across videos, whereas the direction (left or right) that the actor reached to select a piece of fruit was counterbalanced across videos to eliminate the possibility of children interpreting the actor's behaviors as a preference for side rather than as a preference for the target items. Children had four opportunities to guess the actor's favorite fruit or request more information after each trial. Children watched a minimum of two videos (Trial 1 included two videos, and each subsequent trial included only one video), and a maximum of five videos, depending on their accuracy in correctly guessing the actor's favorite fruit (see Table 1). The transitive condition required only two pieces of evidence to solve, both of which were presented at Trial 1. In the other three conditions (consistent, inconsistent, and ambiguous), the information was inconclusive and the favorite fruit could not be deduced from the information provided at Trial 1, necessitating an information-seeking strategy.

Children completed the study at different rates because the study was completed on correctly guessing orange. Therefore, the sample size of the study decreased across trials. Thus, we examined data only from Trials 1 and 2. Children who guessed incorrectly at Trial 1 were also excluded from Trial 2 analyses because feedback about their incorrect guess provided additional information about the actor's favorite. After Trial 2, 163 participants (44.9%) had completed the study by guessing accurately. 126 participants had been removed from the study for an incorrect guess on Trial 1 (34.7%). The remaining 74 participants (20.4%) in the study after Trial 2 were distributed unevenly across conditions, 9 were in the transitive condition, 12 were in the ambiguous condition, 33 were in the inconsistent condition, and 20 were in the consistent condition.

Trial 1

Trial 1 consisted of two videos that were the experimental manipulation. The first piece of evidence shown in the first video was the same across conditions. The video showed the actor seated behind a table with a choice between an apple and a banana. The actor reached out with her right hand to the fruit on her right side to select the banana. After children watched this video, the experimenter informed them that they would watch another video to gain an additional piece of information about the actor's preference. Children in the consistent condition saw the actor choose between an apple and a banana again and make the same selection, a banana. Similarly, participants in the inconsistent condition saw the actor choose between an apple and a banana again, only this time the actor selected the apple. Participants in the ambiguous condition saw the actor choose between an apple and an orange and select the orange. Finally, in the transitive condition, children saw the actor choose between a banana and an orange and select the orange. Children in the transitive condition could deduce the actor's favorite because the first video revealed that the banana is preferred to the apple and the second video revealed that the orange is preferred to the banana (Table 1).

After viewing the two videos at Trial 1, children were presented with a screen that depicted the actor seated behind a table with all three fruit options placed in front of her. On the left-hand side of the screen were graphical representations of the two videos that the children had just seen. Each video was represented by a box that displayed the two fruits that the actor had chosen between in the video, with the selected fruit circled in green and the unselected fruit with a red "X" over it. This was done to reduce the amount of working memory necessary to complete the task. With this screen displayed on the laptop, the experimenter told the participants, "Remember, we have all this fruit here, but we can only give one to [the actor]. So, do you think that you need more information to figure out which one is [the actor's] favorite, or do you think that you know which one is her favorite between the apple, the orange, and the banana?" If participants stated that they knew which fruit was the actor's favorite, the experimenter asked, "Okay, which one do you think is her favorite?" After children made their guess, the experimenter prompted for an explanation of their belief by asking, "Why do you think that one is her favorite?" Children then received feedback on the accuracy of their guess in the form of an additional video depicting the actor stating whether the participants' guess was correct or not.

Trial 2

If participants stated that they needed further information, the experimenter would advance the task on the computer to the next set of videos. At this point, children could choose which kind of evidence they wanted to see next. One option, the new information option, showed the actor selecting between the fruit the participants had just seen selected in the previous video and the fruit that was omitted from the previous video. The other option, the repeat option, simply depicted the actor choosing between the same two pieces of fruit that were depicted in the previous video. Thus, the information children observed at Trial 2 differed by condition. For example, participants in the consistent condition saw two videos at Trial 1, both of which depicted the banana being selected over the apple. Therefore, if children in the consistent condition selected to watch repeat information at Trial 2, they would see a third video showing the banana being chosen over the apple. If they selected new information, they would see a video that showed the actor choosing between the fruit selected in the second video of Trial 1 (banana) and the fruit that was omitted from the second video of Trial 1 (orange). Thus, children in the consistent condition would see the actor selecting between the banana and the orange. By selecting to watch the repeat video, participants gained no new information about the actor's preference; however, selecting the new information allowed participants to determine the actor's favorite fruit more quickly through the process of elimination or transitive reasoning. The option of which video to watch at Trial 2 was presented to children by the experimenter asking, "Okay, let's try to use some more information to figure out [the actor's] favorite fruit. Do you want to see [the actor] choose between [fruits in the new information video] or [fruits in the repeat information video] again?" After choosing and viewing which evidence they wanted to review, the new information option or the repeat option, participants again had the opportunity to request more information or make a guess if they believed they knew the actor's favorite fruit. This process repeated for a total of three videos beyond the Trial 1 videos.

In all conditions, the orange was the actor's favorite fruit, meaning that the actor always selected it any time it was an option. Participants solved the task by accurately guessing orange. If participants guessed incorrectly (banana or apple), they were allowed to continue with the task until they made a correct guess; however, they were removed from Trial 2 analyses because they had obtained additional information by learning that their original guess was wrong.

Coding

The task was videotaped and transcribed. Each time that children made a guess about the actor's preference, their explanation was coded for content. There were five coding categories of explanation that were consolidated out of the explanations that children most commonly provided. The five categories were individual preference, item property, frequency, inferential, and nonexplanatory. Responses that acknowledged the preference of the actor (e.g., "Bananas are her favorite") were coded as *individual preference.* Explanations that appealed to some characteristic of the individual fruit (e.g., "Oranges are very juicy and healthy") were coded as *item property*. Explanations that appealed to the frequency of the events they had witnessed (e.g., "She picked the banana twice") were coded as *frequency*. Explanations that explicitly appealed to transitive reasoning by comparing the frequency between two items (e.g., "Because she picked the banana over the apple and she didn't choose the banana the next time, she chose the orange") were coded as *inferential*. Explanations that were unrelated to the task at hand (e.g., "I eat bananas at lunch") were coded as *nonexplanatory*.

Results

Data on the frequency of participants' requests for additional information by condition and age are presented first. We then report the results of the explanations children provided for their guesses. Finally, we report participants' accuracy on their guesses. We report all the results for Trial 1 first and then proceed to report the results for Trial 2.

Trial 1

Information seeking

The frequency of information seeking by age and condition is presented in Table 2.

Two binomial logistic regression models were conducted on participants' decision to seek more information using both the condition and participants' age as the independent variables. The condition variable was dummy coded using the transitive condition as the baseline, and the data were centered on the mean of age. The first model did not include the interaction between condition and age. The results of the first model show a main effect of age, where the odds that children requested more information increased multiplicatively by 1.33 for every 1-year increase in age (odds ratio = 1.33, 95% confidence interval [CI] = 1.14–1.54). This supports our prediction that information seeking would increase with age. Model 1 also shows a significant difference between conditions where the odds of children in the ambiguous condition seeking more information are 89% greater than the odds of children in the transitive condition seeking more information (odds ratio = 1.89, 95% CI = 1.04–3.45). This provides support to our prediction that ambiguous information would motivate information seeking. Model 1 indicates no differences in children's probability to seek more information between the transitive condition and the consistent condition or between the transitive condition and the inconsistent condition.

With the transitive condition as the baseline, the second model included the interaction term between condition and age. Results from Model 2 indicate a statistically significant interaction between age and condition. Older children in the inconsistent condition were more likely than younger children to seek out more information, whereas there was no effect of age on information seeking for children in the transitive condition (odds ratio = 1.66, 95% CI = 1.07–2.56). This provides some support for our prediction that inconsistent evidence would motivate information seeking, seemingly only for older children. Results of both regression Model 1 and regression Model 2 are presented in the Appendix (Table A1).

Table 2
Percentage of participants seeking more information at Trial 1.

	Consistent	Inconsistent	Ambiguous	Conclusive
5-year-olds	18.2% (4/22)	25.9% (7/27)	45.8% (11/24)	40.7% (11/27)
6-year-olds	18.2% (4/22)	27.8% (5/18)	47.6% (10/21)	33.3% (5/15)
7-year-olds	40.0% (6/15)	71.4% (10/14)	73.3% (11/15)	33.3% (5/15)
8-year-olds	41.2% (7/17)	58.8% (10/17)	47.1% (8/17)	50.0% (9/18)
9-year-olds	46.7% (7/15)	64.3% (9/14)	70.6% (12/17)	38.5% (5/13)
Total	30.8% (28/91)	45.6% (41/90)	55.3% (52/94)	39.8% (35/88)

Note. $N = 363$.

Explanations

Explanations from a random 25% of the sample were coded by an independent coder, and interrater agreement was calculated using Cohen's kappa = .78. At Trial 1, 57% of participants (207 of 363) chose to make a guess after watching the two videos. A chi-square goodness-of-fit test was conducted for each condition to determine whether the different types of evidence led to differences in the frequency with which participants provided each type of explanation. The expected frequency of each explanation type was the total number of explanations provided within each condition divided by the number of possible explanation types. The data show a significant deviation from the expected distribution of explanations in the consistent condition, $\chi^2(4, N = 63) = 31.68$, $p < .0001$. Examination of the standardized residuals shows that participants in the consistent condition gave fewer than expected inferential explanations (−2.99) and more than expected frequency explanations (+4.06). In the inconsistent condition, individual preference and item property explanations were most common, but the data show no significant difference between the observed and expected numbers of each explanation type, $\chi^2(4, N = 49) = 7.43$, $p = .11$. The data from the ambiguous condition show a significant deviation from the expected distribution of explanations $\chi^2(4, N = 42) = 19.43$, $p = .0006$. Examination of the standardized residuals shows that participants in the ambiguous condition gave more than expected individual preference explanations (+2.97) and fewer than expected inferential explanations (−2.90). In the transitive condition, inferential explanations were the most common, but there was no significant deviation from the expected frequency of each explanation type, $\chi^2(4, N = 53) = 8.04$, $p = .09$ (Table 3).

Accuracy

For the 207 participants (57%) who chose to make a guess after watching the two videos at Trial 1, we assessed the accuracy of guesses by age and condition. These data are presented in Table A2 of the Appendix. To examine the effect of age and condition on the accuracy of children's guesses, we conducted two binomial logistic regression models on accuracy using condition and age as independent variables and dummy coded our condition variable so that the transitive condition was the baseline. The data were also centered on the mean of age. The first model did not include an interaction between condition and age. Results of Model 1 show a main effect of age, where the odds that children made an accurate guess increased multiplicatively by 1.55 for every 1-year increase in age (odds ratio = 1.55, 95% CI = 1.22–1.96). This supports our prediction that children's accuracy on the task would increase with age. Model 1 also reveals that at Trial 1, the odds of a child from the transitive condition guessing accurately are about 14.5 times greater than the odds of a child from the consistent condition guessing accurately (odds ratio = 0.07, 95% CI = 0.03–0.19). This provides partial support for our prediction that children in the transitive condition would be more accurate than children in all other conditions.

With the transitive condition as the baseline, Model 2 included the interaction term between condition and age. Results of Model 2 indicate that there was a significant interaction between condition and age. The odds of an accurate response for older children were higher than the odds of an accurate response for younger children in the transitive condition, whereas for children in the consistent condition the odds of an accurate response did not increase with age (odds ratio = 0.33, 95% CI = 0.14–0.75). The results of both regression Model 1 and regression Model 2 are presented in the Appendix (Table A3).

Table 3
Percentage of participants providing each category of explanation at Trial 1.

	Consistent	Inconsistent	Ambiguous	Conclusive
Individual preference	28.1% (18/63)	28.6% (14/49)	40.5% (17/42)	9.4% (5/53)
Item property	9.4% (6/63)	28.6% (14/49)	26.2% (11/42)	20.8% (11/53)
Frequency	42.9% (27/63)	16.3% (8/49)	11.9% (5/42)	26.4% (14/53)
Inferential	3.2% (2/63)	8.2% (4/49)	0% (0/42)	30.2% (16/53)
Unrelated	15.6% (10/63)	18.4% (9/49)	21.4% (9/42)	13.2% (7/53)

Note. N = 207.

Trial 2

Information seeking

After viewing the Trial 1 videos, 22.3% of participants (81 of 363) correctly guessed the actor's favorite fruit, thereby completing the study. Just over one third (34.7%) of participants (126 of 363) made an incorrect guess at Trial 1. These participants were excluded from the Trial 2 analyses because they received additional information in the form of feedback on their incorrect guess. A total of 156 participants requested more information and continued on to Trial 2 (28 [30.8%] from the consistent condition, 41 [45.6%] from the inconsistent condition, 52 [55.3%] from the ambiguous condition, and 35 [39.8%] from the transitive condition). At this point in the procedure, children watched one additional evidence video and were again asked whether they needed more information. The frequency with which children requested more information after viewing the Trial 2 video is presented by age and condition in Table 4.

We examined the frequency of children's requests for more information using the same analyses as Trial 1. Two binomial logistic regression models were conducted on whether children sought out more information using condition and age as the independent variables with the condition variable dummy coded so that the transitive condition was the baseline. The data were centered on the mean of age. Model 1 did not include the interaction between condition and age and revealed that the odds that children in the consistent condition sought out more information were more than seven times greater than the odds that children in the transitive condition sought out more information (odds ratio = 7.13, 95% CI = 2.12–23.99). Model 1 also shows that the odds that children in the inconsistent condition sought out more information were about seven times greater than the odds that children in the transitive condition sought out more information (odds ratio = 7.15, 95% CI = 2.29–22.32).

Using the transitive condition as the baseline, Model 2 included the interaction term between condition and age. Model 2 reveals a significant interaction between condition and age, such that the odds that older children in the inconsistent condition requested more information were greater than the odds that older children in the transitive condition requested more information, whereas there was no difference for the younger children in these conditions (odds ratio = 2.95, 95% CI = 1.11–7.85). The results of both regression Model 1 and regression Model 2 are presented in the Appendix (Table A4).

Explanations

A total of 109 of the 156 participants (69.9%) who continued on to Trial 2 chose to make a guess. A chi-square goodness-of-fit test was conducted to determine whether there were differences in the frequency of each explanation type within each condition. The expected frequency of each explanation type was the total number of explanations provided within each condition divided by the number of possible explanation types. In the consistent condition, the most common explanation type was inferential; however there was no deviation in the frequency of each explanation type from the expected frequency, $\chi^2(4, N = 13) = 5.85$, $p = .21$. Similarly, there was no significant difference in the frequency of explanation types in the inconsistent condition, $\chi^2(4, N = 19) = 0.74$, $p = .94$. Note that due to the small sample size of explanations in the consistent and inconsistent conditions, we do not draw any hard conclusions about children's explanations in these conditions at Trial 2. There was a significant deviation from the expected distribution of explanations in the ambiguous condition,

Table 4
Percentage of participants seeking more information at Trial 2.

	Consistent	Inconsistent	Ambiguous	Conclusive
5-year-olds	25.0% (1/4)	28.6% (2/7)	18.2% (2/11)	36.4% (4/11)
6-year-olds	75.0% (3/4)	60.0% (3/5)	20.0% (2/10)	0.0% (0/5)
7-year-olds	83.3% (5/6)	40.0% (4/10)	0.0% (0/11)	20.0% (1/5)
8-year-olds	28.6% (2/7)	80.0% (8/10)	0.0% (0/8)	0.0% (0/9)
9-year-olds	57.1% (4/7)	55.6% (5/9)	8.3% (1/12)	0.0% (0/5)
Total	53.6% (15/28)	53.7% (22/41)	9.6% (5/52)	14.3% (5/35)

Note. $N = 156$.

Table 5
Percentage of children providing each category of explanation at Trial 2.

	Consistent	Inconsistent	Ambiguous	Conclusive
Individual preference	15.4% (2/13)	26.3% (5/19)	12.8% (6/47)	3.3% (1/30)
Item property	0% (0/13)	15.8% (3/19)	6.4% (3/47)	3.3% (1/30)
Frequency	30.8% (4/13)	15.8% (3/19)	40.4% (19/47)	43.3% (13/30)
Inferential	38.5% (5/13)	21.1% (4/19)	31.9% (15/47)	40.0% (12/30)
Unrelated	15.4% (2/13)	21.1% (4/19)	8.5% (4/47)	10.0% (3/30)

Note. $N = 109$.

$\chi^2(4, N = 47) = 21.83$, $p = .0002$. The standardized residuals show that participants in the ambiguous condition provided more frequency explanations than expected (+3.13) and fewer item property explanations than expected (−2.09). Finally, the data from the transitive condition were significantly different from expected, $\chi^2(4, N = 30) = 24.00$, $p < .0001$. The standardized residuals show that children in the transitive condition provided more frequency explanations than expected (+2.86), more inferential explanations than expected (+2.45), fewer item property explanations than expected (−2.04), and fewer individual preference explanations than expected (−2.04) (Table 5).

Accuracy

A total of 109 participants (69.9% of those who continued on to Trial 2) chose to guess on Trial 2. The accuracy of those guesses by age and condition is presented in Table A5 of the Appendix, split by whether the participants observed new or repeat information. Two binomial logistic regression models using the transitive condition as the baseline were conducted. Both models included condition and age as the independent variables with data centered on the mean of age. Model 1 did not include an interaction, whereas Model 2 included the interaction between condition and age. Model 1 shows that the odds of children in the inconsistent condition guessing accurately were 0.10 times the odds of children in the transitive condition guessing accurately (odds ratio = 0.10, 95% CI = 0.02–0.43). The odds of children in the consistent condition guessing accurately were 0.20 times the odds of children in the transitive condition guessing accurately (odds ratio = 0.20, 95% CI = 0.04–1.00). Model 1 also reveals a main effect of age, such that the odds of guessing accurately increased multiplicatively by 1.47 for every 1-year increase in age (odds ratio = 1.47, 95% CI = 1.05–2.04).

Using the transitive condition as the baseline, Model 2 included the interaction term between condition and age. Model 2 reveals no significant interactions between condition and age. The results of both Model 1 and Model 2 are presented in the Appendix (Table A6).

Discussion

The ability to use evidence and explanation to solve problems presents a significant cognitive challenge for young children. Across four different evidence conditions, we investigated the impact of inconclusive and conclusive evidence on children's information seeking, explanations, and accuracy on a problem-solving task. This study revealed that children's propensity to engage in information seeking, and the type of explanations children generate, both are heavily influenced by the type of evidence they observe.

Our first objective was to examine how different kinds of evidence influence information seeking in the service of problem solving. We assessed whether children thought they could solve the task based on the evidence or needed more information. Across conditions, although children had a strong preference to seek out new information in response to negative feedback, the kind of inconclusive evidence mattered. We predicted that information that was inconsistent or ambiguous would motivate more information seeking after Trial 1 compared with evidence that was conclusive, whereas consistent information would not. Our results supported these predictions; across age groups, we found that ambiguous evidence was more likely to motivate children to request information after Trial 1 than conclusive (transitive) evidence, whereas consistent evidence was not. This comports with previous research demonstrating that ambiguous evidence is more likely to motivate exploration than unambiguous evidence (Cook et al., 2011). Ambiguous evidence may cue children to uncertainty and prompt further information seeking. We also found that inconsistent evidence was more likely to motivate requests for more information than conclusive evidence, but only for older children. This is consistent with previous research demonstrating that inconsistent evidence motivates both exploration and explanation (Legare, 2014; Legare et al., 2010) but suggests that the recognition of inconsistency as a cue to uncertainty may develop over the course of early childhood. Our data indicate that ambiguous evidence and inconsistent evidence motivate information seeking to a greater extent than conclusive evidence.

As predicted, our data also demonstrate that older children are more likely to seek out information than younger children. For all inconclusive evidence conditions, we discovered an age-related increase in information seeking after Trial 1. For the conclusive evidence condition, information seeking did not vary across age. This suggests that from 5 to 9 years of age, children are developing their ability to identify and respond to the uncertainty inherent in inconclusive evidence. This result is consistent with previous research demonstrating that until around 6 years of age, children have a tendency to overestimate their own level of knowledge (Beck & Robinson, 2001; Kloo et al., 2017). Evidence that is inconclusive yet consistent, poses a particularly difficult challenge for children of this age, most of whom may fail to recognize that the information is incomplete. Thus, although the ability to seek out information in response to evidence improves over the course of early childhood, even young children are sensitive to the kind of evidence they observe.

Our second objective was to examine how children use explanations in response to evidence. We assessed whether the types of explanations children gave differed across conditions and trials. We predicted that children would generate explanations that were specific to the type of evidence they had observed. Across conditions and age groups, our results show that, indeed, children are flexible in their use of explanation, which reflects the kind of evidence they observe. We found that, compared with other conditions, children in the transitive condition provided significantly more inferential explanations than expected at Trial 1. This result is consistent with previous research documenting children's early developing intuitions about transitive inference (Hawkins, Pea, Glick, & Scribner, 1984; Markovits, Schleifer, & Fortier, 1989; Mou et al., 2014). We also found that, compared with other conditions, the consistent condition motivated more frequency explanations than expected at Trial 1, demonstrating children's sensitivity to statistical regularities.

Our third objective was to examine how different kinds of evidence facilitate or inhibit children's problem-solving success. We examined children's problem-solving accuracy by condition and age. We predicted that children who observed transitive evidence would be more accurate than children who observed all other types of evidence and that children's problem-solving accuracy would increase with age. Our findings partially support these predictions, revealing that particular kinds of evidence had distinct effects on problem-solving accuracy. Children in the transitive condition were more likely to accurately complete the task than children in the consistent condition at Trial 1 and were more likely to accurately complete the task than children in the consistent and inconsistent conditions at Trial 2. Accuracy in the ambiguous condition was no different from accuracy in the transitive condition at Trial 2. Ambiguity motivated children to seek out information at Trial 1 and engage in transitive inference to achieve high levels of accuracy at Trial 2.

Our data demonstrate that the capacity to use evidence in problem solving undergoes significant development between 5 and 9 years of age. Older children in the transitive condition were more likely to draw an accurate conclusion than younger children. Although previous research demonstrates that infants have an intuitive understanding of transitive inference (Mou et al., 2014), our task required children to assess their own level of knowledge and articulate their reasoning. This result is consistent with the possibility that articulating transitive inference may be much later developing, around 7 to 9 years of age. Thus, although infants are skilled at understanding transitive inference, the ability to articulate this type of reasoning improves substantially over the course of early childhood.

The results of this research generate several questions for future research. In this study, we provided children with different kinds of carefully controlled evidence designed to reduce the task demands on working memory. Future research should examine how children use evidence and explanation in contexts where the patterns of evidence reflect a greater variety of evidence and how they engage in more open-ended tasks where there is greater freedom to seek out information. Another direction for future research is to examine problem solving using different topics. Because our intention was to examine how children reason about evidence that could be explained in different ways (inferential vs. individual preference vs. item property) we chose to examine food preference. Examining how children reason about evidence in a similar preference paradigm using novel objects could provide additional insight into how children use evidence and explanation to solve problems. Future research should also examine children's explanations not only when they draw a conclusion but also when they request more information. Some children in the transitive condition may have engaged in information seeking simply to confirm the accuracy of their guess, whereas children in the inconclusive conditions may seek information out of necessity. Finally, future research should examine how information seeking and explanation generation are related to one another. Does the process of generating an explanation aid children in their ability to evaluate whether they need more information before drawing a conclusion? Or are explanation and information seeking simply two unrelated mechanisms that operate independently to contribute to children's learning?

Conclusion

Taken together, our results suggest that different types of evidence motivate children to use different problem-solving strategies. Inconsistent evidence and ambiguous evidence were more likely to motivate children to engage in the process of inquiry by seeking information. This is in line with previous literature that highlights children's ability to track probabilities and learn from probabilistic data (Cook et al., 2011; Kushnir & Gopnik, 2007; Legare et al., 2010, 2016; Schulz & Bonawitz, 2007). In response to consistent and conclusive evidence, children were more likely to draw conclusions without engaging in additional inquiry. Examining how children respond to different types of evidence provides insight into understanding the complex interplay among acquiring, evaluating, and applying information to solve problems.

Acknowledgements

Funding from The John Templeton Foundation, USA, IH-118 and The National Science Foundation, USA, DRL-1420241 to Cristine H. Legare. Special thank you to Adrian Abellanoza, Jennifer Clegg, Courtney Crosby, Emily Eck, Eric Harvey, Irene Jea, Emily Shanks, & Kasia Szostak for their assistance with data collection. Finally, thank you to the children who participated in the study and to the Thinkery for facilitating data collection.

Appendix A

See Table A1–A6.

Table A1
Logistic regression results on information seeking at Trial 1.

Parameter	Model 1 (no interaction)				Model 2 (interaction)			
	β (*SE*)	Odds	Lower	Upper	β (*SE*)	Odds	Lower	Upper
Intercept	−.43 (.22)	0.65	0.42	1.00	−.42 (.22)	0.66	0.43	1.01
Consistent	−.40 (.32)	0.67	0.36	1.25	−.45 (.32)	0.64	0.34	1.20
Ambiguous*	.64 (.31)	1.89	1.04	3.45	.62 (.30)	1.86	1.03	3.36
Inconsistent	.27 (.31)	1.31	0.71	2.41	.26 (.32)	1.30	0.70	2.41
Age**	.28 (.08)	1.33	1.14	1.54	.04 (.15)	1.04	0.78	1.40
Consistent × Age	–	–	–	–	.36 (.22)	1.43	0.92	2.22
Ambiguous × Age	–	–	–	–	.14 (.20)	1.16	0.77	1.72
Inconsistent × Age*	–	–	–	–	.50 (.22)	1.66	1.07	2.56

* $p < .05$.
** $p < .01$.

Table A2
Percentage of participants making a correct guess after Trial 1.

	Consistent	Inconsistent	Ambiguous	Conclusive
5-year-olds	16.7% (3/18)	40.0% (8/20)	23.1% (3/13)	43.8% (7/16)
6-year-olds	11.1% (2/18)	23.1% (3/13)	36.4% (4/11)	40.0% (4/10)
7-year-olds	0.0% (0/9)	75.0% (3/4)	75.0% (3/4)	60.0% (6/10)
8-year-olds	10.0% (1/10)	57.1% (4/7)	55.6% (5/9)	88.9% (8/9)
9-year-olds	12.5% (1/8)	80.0% (4/5)	80.0% (4/5)	100.0% (8/8)
Total	11.1% (7/63)	44.9% (22/49)	45.2% (19/42)	62.3% (33/53)

Note. $N = 207$.

Table A3
Logistic regression results on accuracy at Trial 1.

Parameter	Model 1 (no interaction)				Model 2 (interaction)			
	β (*SE*)	Odds	Lower	Upper	β (*SE*)	Odds	Lower	Upper
Intercept[†]	.57 (.30)	1.76	0.98	3.16	.74 (.36)	2.10	1.05	4.22
Consistent[**]	−2.67 (.51)	0.07	0.03	0.19	−2.92 (.57)	0.05	0.02	0.16
Ambiguous	−.70 (.44)	0.50	0.21	1.18	−.86 (.49)	0.42	0.16	1.10
Inconsistent	−.53 (.42)	0.59	0.26	1.35	−.77 (.48)	0.46	0.18	1.18
Age[**]	.44 (.12)	1.55	1.22	1.96	.88 (.28)	2.42	1.41	4.15
Consistent × Age[**]	–	–	–	–	−1.11 (.42)	0.33	0.14	0.75
Ambiguous × Age	–	–	–	–	−.34 (.36)	0.71	0.35	1.46
Inconsistent × Age	–	–	–	–	−.57 (.36)	0.57	0.28	1.14

[†] $p < .06$.
[**] $p < .01$.

Table A4
Logistic regression results on information seeking at Trial 2.

Parameter	Model 1 (no interaction)				Model 2 (interaction)			
	β (*SE*)	Odds	Lower	Upper	β (*SE*)	Odds	Lower	Upper
Intercept[**]	−1.81 (.49)	0.16	0.06	0.42	−2.44 (.78)	0.09	0.02	0.40
Consistent[**]	1.96 (.62)	7.13	2.12	23.99	2.58 (.87)	13.24	2.42	72.49
Ambiguous	−.44 (.67)	0.65	0.17	2.42	.07 (.94)	1.08	0.17	6.76
Inconsistent[**]	1.97 (.58)	7.15	2.29	22.32	2.53 (.84)	12.56	2.41	65.54
Age	−.06 (.13)	0.94	0.73	1.23	−.77 (.44)	0.46	0.19	1.11
Consistent × Age	–	–	–	–	.75 (.52)	2.11	0.76	5.81
Ambiguous × Age	–	–	–	–	.44 (.55)	1.55	0.52	4.61
Inconsistent × Age[*]	–	–	–	–	1.08 (.50)	2.95	1.11	7.85

[*] $p < .05$.
[**] $p < .01$.

Table A5
Percentage of participants making an accurate guess after Trial 2.

	Consistent		Inconsistent		Ambiguous		Conclusive	
	Repeat	New	Repeat	New	Repeat	New	Repeat	New
5-year-olds	0% (0/2)	100% (1/1)	0% (0/1)	50.0% (2/4)	33.3% (1/3)	100% (6/6)	N/A (0/0)	71.4% (5/7)
6-year-olds	N/A (0/0)	100% (1/1)	N/A (0/0)	50.0% (1/2)	33.3% (1/3)	100% (5/5)	100% (2/2)	33.3% (1/3)
7-year-olds	N/A (0/0)	0% (0/1)	0% (0/2)	50.0% (2/4)	0% (0/1)	90.0% (9/10)	N/A (0/0)	100.0% (4/4)
8-year-olds	N/A (0/0)	80.0% (4/5)	N/A (0/0)	100% (2/2)	N/A (0/0)	87.5% (7/8)	100% (2/2)	100.0% (7/7)
9-year-olds	N/A (0/0)	66.7% (2/3)	0% (0/2)	50.0% (1/2)	N/A (0/)	100.0% 11/11	100% (2/2)	100.0% (3/3)
Total	0% (0/2)	72.7% (8/11)	0% (0/5)	57.1% (8/14)	28.6% (2/7)	95% (38/40)	100% 6/6	83.3% (20/24)

Note. $N = 109$.

Table A6
Logistic regression results on accuracy at Trial 2.

Parameter	Model 1 (no interaction)				Model 2 (interaction)			
	β (*SE*)	Odds	Lower	Upper	β (*SE*)	Odds	Lower	Upper
Intercept**	2.02 (.56)	7.53	2.51	22.57	2.56 (.89)	12.87	2.27	73.02
Consistent*	−1.60 (.82)	0.20	0.04	1.00	−2.14 (1.06)	0.12	0.01	0.95
Ambiguous	−.16 (.69)	0.85	0.22	3.29	−.61 (1.01)	0.55	0.08	3.95
Inconsistent**	−2.30 (.74)	0.10	0.02	0.43	−2.87 (1.0)	0.06	0.01	0.40
Age*	.38 (.17)	1.47	1.05	2.04	.90 (.50)	2.46	0.93	6.48
Consistent × Age	–	–	–	–	−.56 (.63)	0.57	0.17	1.96
Ambiguous × Age	–	–	–	–	−.38 (.58)	0.68	0.22	2.15
Inconsistent × Age*	–	–	–	–	−.90 (.58)	0.41	0.13	1.26

* $p < .05$.
** $p < .01$.

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2019.01.007.

References

Amsel, E., & Brock, S. (1996). The development of evidence evaluation skills. *Cognitive Development, 11*, 523–550.
Baillargeon, R. (2002). The acquisition of physical knowledge in infancy: A summary in eight lessons. In U. Goswami (Ed.), *Blackwell handbook of childhood cognitive development* (pp. 47–83). Oxford, UK: Blackwell.
Beck, S. R., & Robinson, E. J. (2001). Children's ability to make tentative interpretations of ambiguous messages. *Journal of Experimental Child Psychology, 79*, 95–114.
Bjorklund, D. B., Dukes, C., & Brown, R. D. (2009). The development of memory strategies. In M. Courage & N. Cowan (Eds.), *The development of memory in infancy and childhood* (pp. 145–175). Hove, UK: Psychology Press.
Bonawitz, E. B., Fischer, A., & Schulz, L. (2012). Teaching 3.5-year-olds to revise their beliefs given ambiguous evidence. *Journal of Cognition and Development, 13*, 266–280.
Bonawitz, E., Shafto, P., Gweon, H., Goodman, N. D., Spelke, E., & Schulz, L. (2011). The double-edged sword of pedagogy: Instruction limits spontaneous exploration and discovery. *Cognition, 120*, 322–330.
Chi, M. T. H., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13*, 145–182.
Chouinard, N. M. (2007). Children's questions: A mechanism for cognitive development. *Monographs of the Society of Child Development, 72*(1, Serial No. 286).
Cook, C., Goodman, N., & Schulz, L. (2011). Where science starts: Spontaneous experiments in preschoolers' exploratory play. *Cognition, 120*, 341–349.
Corriveau, K. H., & Kurkul, K. E. (2014). Why does rain fall? Children prefer to learn from an informant who uses noncircular explanations. *Child Development, 85*, 1827–1835.
Courage, M. L. (1989). Children's inquiry strategies in referential communication and in the game of Twenty Questions. *Child Development, 60*, 877–886.
Coyle, T. R., & Bjorklund, D. F. (1997). Age differences in, and consequences of, multiple- and variable-strategy use on a multitrial sort–recall task. *Developmental Psychology, 33*, 372–380.
Einav, S., & Robinson, E. J. (2010). Children's sensitivity to error magnitude when evaluating informants. *Cognitive Development, 25*, 218–232.
Fay, A. L., & Klahr, D. (1996). Knowing about guessing and guessing about knowing: Preschoolers' understanding of indeterminacy. *Child Development, 67*, 689–716.
Foster, M. I., & Keane, M. T. (2015). Why some surprises are more surprising than others: Surprise as a metacognitive sense of explanatory difficulty. *Cognitive Psychology, 81*, 74–116.
Frazier, B. N., Gelman, S. A., & Wellman, H. M. (2009). Preschoolers' search for explanatory information within adult–child conversation. *Child Development, 80*, 1592–1611.
Gazes, R. P., Hampton, R. R., & Lourenco, S. F. (2017). Transitive inference of social dominance by human infants. *Developmental Science, 20*, e12367.
Gopnik, A., Sobel, D. M., Schulz, L. E., & Glymour, C. (2001). Causal learning mechanisms in very young children. Two-, three-, and four-year-olds infer causal relations from patterns of variation and covariation. *Developmental Psychology, 37*, 620–629.
Gweon, H., Pelton, H., Konopka, J. A., & Schulz, L. E. (2014). Sins of omission: Children selectively explore when teachers are under-informed. *Cognition, 132*, 335–341.
Halford, G. S. (1984). Can young children integrate premises in transitivity and serial order tasks? *Cognitive Psychology, 16*, 65–93.
Harnishfeger, K. K., & Bjorklund, D. F. (1990). Children's strategies: A brief history. In D. F. Bjorklund (Ed.), *Children's strategies: Contemporary views of cognitive development* (pp. 1–22). Hillsdale, NJ: Lawrence Erlbaum.

Hawkins, J., Pea, R. D., Glick, J., & Scribner, S. (1984). "Merds that laugh don't like mushrooms": Evidence for deductive reasoning in preschoolers. *Developmental Psychology, 20*, 584–594.
Hempel, C. G. (1965). *Aspects of scientific explanation and other essays in the philosophy of science*. New York: Free Press.
Hilton, D. J. (1995). The social context of reasoning: Conversational inference and rational judgment. *Psychological Bulletin, 118*, 248–271.
Klahr, D., & Dunbar, K. (1988). Dual space search during scientific reasoning. *Cognitive Science, 12*, 1–48.
Kloo, D., Rohwer, M., & Perner, J. (2017). Direct and indirect admission of ignorance by children. *Journal of Experimental Child Psychology, 159*, 279–295.
Koslowski, B., Marasia, J., Chelenza, M., & Dublin, R. (2008). Information becomes evidence when an explanation can incorporate it into a causal framework. *Cognitive Development, 23*, 472–487.
Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). *The development of scientific thinking skills*. Orlando, FL: Academic Press.
Kushnir, T., & Gopnik, A. (2007). Conditional probability versus spatial contiguity in causal learning: Preschoolers use new contingency evidence to overcome prior spatial assumptions. *Developmental Psychology, 43*, 186–196.
Legare, C. H. (2012). Exploring explanation: Explaining inconsistent information guides hypothesis-testing behavior in young children. *Child Development, 83*, 173–185.
Legare, C. H. (2014). The contributions of explanation and exploration to children's scientific reasoning. *Child Development Perspectives, 8*, 101–106.
Legare, C. H., & Gelman, S. A. (2014). Examining explanatory biases in young children's biological reasoning. *Journal of Cognition and Development, 15*, 287–303.
Legare, C. H., Gelman, S. A., & Wellman, H. M. (2010). Inconsistency with prior knowledge triggers children's causal explanatory reasoning. *Child Development, 81*, 929–944.
Legare, C. H., & Lombrozo, T. (2014). Selective effects of explanation on learning during early childhood. *Journal of Experimental Child Psychology, 126*, 198–212.
Legare, C. H., Mills, C. M., Souza, A. L., Plummer, L. E., & Yasskin, R. (2013). The use of questions as problem-solving strategies during early childhood. *Journal of Experimental Child Psychology, 114*, 63–76.
Legare, C. H., Schult, C., Impola, M., & Souza, A. L. (2016). Young children revise explanations in response to new evidence. *Cognitive Development, 39*, 45–56.
Legare, C. H., Sobel, D. M., & Callanan, M. (2017). Causal learning is collaborative: Examining explanation and exploration in social contexts. *Psychonomic Bulletin & Review, 24*, 1548–1554.
Markovits, H., Schleifer, M., & Fortier, L. (1989). Development of elementary deductive reasoning in young children. *Developmental Psychology, 25*, 787–793.
Mills, C. M., Legare, C. H., Bills, M., & Mejias, C. (2010). Preschoolers use questions as a tool to acquire knowledge from different sources. *Journal of Cognition and Development, 11*, 533–560.
Mills, C. M., Legare, C. H., Grant, M. G., & Landrum, A. R. (2011). Determining who to question, what to ask, and how much information to ask for: The development of inquiry in young children. *Journal of Experimental Child Psychology, 110*, 539–560.
Mou, Y., Province, J. M., & Luo, Y. (2014). Can infants make transitive inferences? *Cognitive Psychology, 68*, 98–112.
Pearl, J. (2009). *Causality: Models, reasoning, and inference*. New York: Cambridge University Press.
Piekny, J., & Maehler, C. (2012). Scientific reasoning in early and middle childhood: The development of domain-general evidence evaluation, experimentation, and hypothesis generation skills. *British Journal of Developmental Psychology, 31*, 153–179.
Pillow, B. H. (2002). Children's and adults' evaluation of the certainty of deductive inferences, inductive inferences, and guesses. *Child Development, 73*, 779–792.
Rittle-Johnson, B., Saylor, M., & Swygert, K. E. (2008). Learning from explaining: Does it matter if mom is listening? *Journal of Experimental Child Psychology, 100*, 215–224.
Ruggeri, A., & Lombrozo, T. (2015). Children adapt their questions to achieve efficient search. *Cognition, 143*, 203–216.
Ruggeri, A., Lombrozo, T., Griffiths, T. L., & Xu, F. (2016). Sources of developmental change in the efficiency of information search. *Developmental Psychology, 52*, 2159–2173.
Ruggeri, A., Sim, Z. L., & Xu, F. (2017). "Why is Toma late to school again?" Preschoolers identify the most informative questions. *Developmental Psychology, 53*, 1620–1632.
Schauble, L. (1996). The development of scientific reasoning in knowledge-rich contexts. *Developmental Psychology, 32*, 102–119.
Schulz, L. (2012). The origins of inquiry: Inductive inference and exploration in early childhood. *Trends in Cognitive Science, 16*, 382–389.
Schulz, L. E., & Bonawitz, E. B. (2007). Serious fun: Preschoolers engage in more exploratory play when evidence is confounded. *Developmental Psychology, 43*, 1045–1050.
Schulz, L. E., & Gopnik, A. (2004). Causal learning across domains. *Developmental Psychology, 40*, 162–176.
Schwenck, C., Bjorklund, D. F., & Schneider, W. (2009). Developmental and individual differences in young children's use and maintenance of a selective memory strategy. *Developmental Psychology, 45*, 1034–1050.
Shrager, J., & Siegler, R. S. (1998). A model of children's strategy choices and strategy discoveries. *Psychological Science, 9*, 405–410.
Siegler, R. S. (2005). Children's learning. *American Psychologist, 60*, 769–778.
Sobel, D. M., & Legare, C. H. (2014). Causal learning in children. *Wiley Interdisciplinary Reviews: Cognitive Science, 5*, 413–427.
Stahl, A. E., & Feigenson, L. (2015). Observing the unexpected enhances infants' learning and exploration. *Science, 348*, 91–94.
Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *Science, 185*, 1124–1131.
van Schijndel, T. J. P., Visser, I., van Bers, B. M. C. W., & Raijmakers, M. E. J. (2015). Preschoolers perform more informative experiments after observing theory-violating evidence. *Journal of Experimental Child Psychology, 131*, 104–119.
Vasconcelos, M. (2008). Transitive inference in non-human animals: An empirical and theoretical analysis. *Behavioral Processes, 78*, 313–334.

Walker, C. M., Lombrozo, T., Legare, C. H., & Gopnik, A. (2014). Explaining prompts children to privilege inductively rich properties. *Cognition, 133*, 343–357.
Walker, C. M., Williams, J. J., Lombrozo, T., & Gopnik, A. (2012). Explaining influences children's reliance on evidence and prior knowledge in causal induction. In N. Miyake, D. Peebles, & R. P. Cooper (Eds.), Proceedings of the 34th Annual Conference of the Cognitive Science Society (pp. 1114–1119). Austin, TX: Cognitive Science Society.
Wellman, H. M. (2011). Reinvigorating explanations for the study of early cognitive development. *Child Development Perspectives, 5*, 33–38.
Wilkenfeld, D. A., & Lombrozo, T. (2015). Inference to the best explanation (IBE) versus explaining for the best inference (EBI). *Science and Education, 24*, 1059–1077.
Willard, A. K., Busch, J. T. A., Cullum, K. A., Letourneau, S. M., Sobel, D. M., Callanan, M. A., & Legare, C. H. (in press). Explain this, explore that: A study of parent–child interaction in a children's museum. Child Development.