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Counterfactual Syllogistic Reasoning in Normal 4-Year-Olds, Children with Learning Disabilities, and Children with Autism

Hilary J. Leevers

Rutgers University

and

Paul L. Harris

University of Oxford, Oxford, United Kingdom

Instruction encouraging imagery improves logical reasoning with counterfactual premises by normal preschool children. In contrast, children with autism have been reported to reason accurately with counterfactual premises in the absence of such instruction (F. J. Scott, S. Baron-Cohen, & A. M. Leslie, 1999). To investigate this pattern of findings, we compared the performance of children with autism, children with learning disabilities, and normally developing 4-year-olds, who were given reasoning problems both with and without instruction in two separate testing sessions 2 to 3 weeks apart. Overall, instruction to use imagery led to persistent logical performance. However, children with autism displayed a distinctive pattern of responding, performing around chance levels, showing a simple response bias, and rarely justifying their responses by elaborating on the premises. We propose that instruction boosts logical performance by clarifying the experimenter's intention that a false proposition be accepted as a basis for reasoning and that children with autism have difficulty grasping this intention.

Key Words: logical reasoning; autism; syllogistic reasoning; counterfactual thought; intentional understanding.

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Address correspondence and reprint requests to Hilary J. Leevers, Center for Molecular and Behavioral Neuroscience, Aidekman Research Center, Rutgers University, 197, University Avenue, Newark, NJ 07102. E-mail: leevers@axon.rutgers.edu.

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Many investigators have claimed that young preschool children are unable to consider the logical implication of a proposition independent of its truth in the real world (Braine, 1990; Braine & Rumain, 1983; Inhelder & Piaget, 1958, 1964; Piaget, 1970, 1972). Instead, they display an "empirical bias" (Scribner, 1977), drawing conclusions on the basis of real-world knowledge. For example, given a syllogistic problem with a counterfactual major premise, "All cats bark. Rex is a cat. Does Rex bark?," young children with no formal schooling typically answer from their empirical knowledge, stating that Rex does not bark because Rex is a cat and cats do not bark, rather than basing their responses on the information in the premises. Nevertheless, recent research has shown that young children can be prompted to set aside their empirical bias. For instance, Dias and Harris (1988, 1990) report that when 4-year-olds are instructed to "make a picture in their heads" of the major premise of each problem, they are more likely to give logical answers to problems with counterfactual premises. Consistent with that logical strategy, instructed children are also more likely to justify their replies by referring to the premises as stated rather than by referring to their empirical knowledge.

In fact, a variety of prompts have successfully elicited logical responding from young children, including 2-year-olds: the use of invented content (Hawkins, Pea, Glick, & Scribner, 1984); presentation of the material in a fantasy context, such as a distant planet (Dias & Harris, 1988, 1990; Dias & Roazzi, 1996; Markovits & Vachon, 1989; Richards & Sanderson, 1999); presentation of the premises in a dramatic make-believe intonation (Dias & Harris, 1990); and instructions to use imagery (Dias & Harris, 1990; Dias & Roazzi, 1996; Markovits & Vachon, 1989; Richards & Sanderson, 1999). A plausible interpretation of the effect of these various prompts is that they encourage children to enter into a temporary make-believe mode of processing within which real-world considerations do not apply (Dias & Harris, 1988, 1990). Markovits (1993, 1995) proposes a related explanation, arguing that when children are presented with a counterfactual premise in a make-believe context, they construct a "cognitive filter." This filter prevents the retrieval from semantic memory of contradictory empirical knowledge that might otherwise be incorporated into their representation of the premises. Hence, accurate logical responding is more likely.

However, the underlying mechanism by which performance is improved may be more general than is implied by either of these two proposals. Manipulations that improve logical responding may do so by clarifying the experimenter's intention that the premises be accepted and used as a basis for reasoning, irrespective of their real-world status (Harris & Leevers, 2000; Leevers & Harris, 1999). When the major premise is false, the experimenter's intention that it be accepted is difficult to grasp because he or she violates the conventions of conversation. Normally, when a speaker asserts a proposition that is false, the speaker is either genuinely mistaken or uses a linguistic marker to explicitly indicate that the proposition is relevant despite its falsity (e.g., "If . . . ," "Suppose that . . ."). Factors that encourage children to focus on the major premise (i.e., instructions to think about, or form an image of, that premise) are also likely to convey that even though these premises are untrue the experimenter considers them to be important and relevant (Sperber & Wilson, 1983). In line with this emphasis on the nature of the exchange between experimenter and participant, research with adults indicates that when they approach a reasoning problem, a relevance heuristic is applied. On the basis of linguistic and pragmatic factors and the salience of features in task presentation, only information that appears relevant is considered (Evans, Newstead, & Byrne, 1993). If children conclude that the major premise is relevant, following the experimenter's emphasis upon it, they should be more likely to accept that premise as a basis for reasoning and more likely to produce a logical response. Thus, according to this analysis, instructions that encourage the use of make-believe or imagery increase logical responding by reducing children's confusion over the experimenter's intention in asserting a proposition that is false.

One way to assess how instruction facilitates logical responding is to examine the performance of children with autism. Autism is a developmental syndrome, normally emerging in the first few years of life, characterized by impairment in language, social interaction, and make-believe (Sigman, 1994). Although children with autism are able to comprehend pretend transformations enacted by an adult (Kavanaugh & Harris, 1994), their production of pretend play is typically delayed and confined to stereotypic routines (Baron-Cohen, 1989; Leslie, 1988; Leslie & Roth, 1993). Children with autism are also delayed in the acquisition of language and some do not develop expressive language. Even among those who do acquire expressive language, there are particular difficulties with the pragmatics of conversation. Children, and indeed adults, with autism are prone to place a literal interpretation upon an utterance, ignoring the intention behind it (Frith, 1989; Happé, 1993; Howlin, 1997). It should be noted that individuals with autism participating in experimental work, such as that discussed in this paper, typically have relatively well-developed language and cognitive skills and may not be representative of the population as a whole.

To date, we are aware of one experiment documenting the ability of children with autism to reason with counterfactual, syllogistic problems. Scott, Baron-Cohen, and Leslie (1999) compared the counterfactual reasoning of normal 4-year-olds, children with autism, and children with moderate learning disabilities (children in the latter two groups had a receptive verbal mental age of 4 to 6 years). Children were tested with and without further instructions to use imagery. All three groups performed moderately well in the imagery condition. Unexpectedly, however, the children with autism gave more logical replies than the other children in the no-imagery condition. Thus, children with autism were competent at logical reasoning even in the absence of instruction encouraging the use of imagery. Indeed, the performance of the autistic group was better without rather than with instruction, suggesting that instructions to use imagery disrupted the otherwise logical performance of this group. It is not clear what element of the instructions caused this effect; the children with autism reported that they were complying with the instruction to form an image (of a flying pig), although they had little insight into the nature of this image (i.e., that it was not real and that the experimenter could not see it).

The relatively successful performance by children with autism in the no-imagery condition casts doubt on the proposal that a make-believe stance is important if children are to reason accurately from counterfactual premises. Nevertheless, the experiment of Scott et al. (1999) has several methodological shortcomings that could put the results into question. First, all 10 of the problems were correctly answered by affirmation (as in the example given in the opening paragraph). Thus, perfect performance could be produced by children with a "yes" response bias. Second, the structure of some of the problems was questionable. Four of the 10 problems appropriately required integration of the major premise (e.g., "All cats bark.") and the minor premise (e.g., "Rex is a cat.") in order to evaluate the concluding question concerning Rex (e.g., "Does Rex bark?"). The remaining 6 problems, however, could be answered without integration of the major premise (e.g., "All snow is black.") and the minor premise (e.g., "Tom touches some snow.") to evaluate the concluding question (e.g., "Is the snow black?"). These latter problems could be answered without any consideration of the minor premise because the concluding question could be directly related to the major premise. Although there was no apparent difference in performance between the two problem types, the simpler sort of problem may have encouraged children to use a response strategy not dependent upon logical reasoning. Finally, different sets of problems were presented in the imagery and the no-imagery conditions, without counterbalancing. Hence, the observed differences between the conditions were confounded with problem content. The experiment reported here was designed to investigate the findings of Scott et al. (1999) with an improved experimental design.

Another way to examine the role of instructions in counterfactual reasoning is to investigate their long-term impact. Although instruction to use imagery might encourage the adoption of a make-believe stance or a cognitive filter toward material presented immediately following that instruction, it is unlikely to do so over days or weeks. First, as Leslie (1987) pointed out, a make-believe stance calls for a special form of processing in order to deal with propositions such as "This banana is a telephone." Extension of this mode of processing beyond a given episode of pretend play would lead to conceptual confusion. After all, in the ordinary world, bananas and telephones belong to quite different categories. Consistent with Leslie's emphasis on the distinctive and transient nature of such pretend processing, Harris and Kavanaugh (1993) found that preschoolers did not sustain a make-believe substitution (e.g., treating a block as if it were a bar of soap) once the pretend episode was brought to an end. On the other hand, if the primary effect of instruction is to clarify the experimenter's intention, that clarification might have an enduring rather than a temporary effect. Indeed, earlier experimental work has suggested that the effects of instructions can persist for up to 1 week (Leevers & Harris, 1999). However, because children always received the instructed session prior to the uninstructed session, it is possible that they were performing in the second session in the same way as they had in the first. In the experiment to be reported here, we elaborated on earlier work, first, by introducing a longer 2- to 3-week break between sessions and, second, by counterbalancing the order of the instructed and uninstructed sessions across children.

EXPERIMENT

The experiment was designed to examine two issues: first, whether children with autism, a syndrome traditionally associated with limited make-believe abilities, can reason from counterfactual premises, either with or without instruction, and, second, whether instruction induces a brief change or a persistent change in reasoning strategy when children are asked to reason from such premises. The performance of normally developing 4-year-olds was compared with that of children with moderate learning disabilities and that of children with autism, all matched for receptive verbal mental age (VMA). All the children answered two sets of counterfactual reasoning problems based on modus ponens (children were previously questioned about the content of the major premises to check that they considered them false). One set of problems was accompanied by instruction to use imagery and the other by no special instructions. There was a break of 2 to 3 weeks between the conditions, which were delivered in counterbalanced order across participants within each of the three groups. The experiment used two sets of eight problems, counterbalanced with condition and group. Half of the problems within each set were correctly answered by affirmation and the other half, by denial. All of the problems required consideration of both of the premises to reach a response.

In line with the proposal that instruction clarifies the experimenter's intention that a false proposition should be accepted as a starting point for reasoning, it was predicted that instruction to create an image of a false proposition would lead to an improvement in logical performance that would carry over from the first session to the second. In addition, it was predicted that children initially answering the problems without instruction would use an empirical approach in that session, but go on to use a logical approach in the second, instructed session. Further, we suggest that if the primary difficulty displayed by children with autism is in understanding a speaker's intention, they will have difficulty in interpreting the task. Hence, they should respond unsystematically, even with further instruction. Alternatively, if children with autism have more difficulty with make-believe, they will be unlikely to show logical performance following imagery instruction, and we would expect them to answer empirically, from their real-world knowledge, in both sessions. Note that both of these predictions differ

TABLE 1
Mean and Range of Receptive Verbal Mental Age and Chronological Age and Ratio of Males to Females, Shown by Participant Group

	Receptive verbal mental age		Chronological age		
Group	Mean	Range	Mean	Range	Male:female
Normal	5,0 (7.8)	4,0–6,0	4,5 (4.2)	4,0–4,11	6:10
MLD[a]	5,2 (6.2)	4,0–6,0	11,7 (16)	9,11–14,4	10:6
Autistic	5,0 (12)	4,0–8,0	11,2 (25)	7,9–15,2	13:3

Note. Standard deviations, in months, are in parentheses.
[a] MLD = moderate learning disability.

from the results of Scott et al. (1999), who found that children with autism answered more problems logically in the uninstructed session than following imagery instructions.

Method

Participants. There were three groups of 16 children: a group of normally developing 4-year-olds from an Oxford nursery school (the normal group), a group of children with moderate learning disabilities from an Oxford school for children with learning disabilities (the MLD group), and a group of children who had been diagnosed with autism by local health services and were attending four centers for children with autism in and around Oxford (the autistic group). The children with moderate learning disabilities included one child with Down's syndrome, but were of mixed and mostly unknown etiology—children with Fragile X syndrome or Asperger's syndrome were not included. A pool of children within each school or center who had parental consent to participate in the study were assessed with the Test for Reception of Grammar (TROG; Bishop, 1982) to provide a measure of receptive VMA. The 16 children diagnosed with autism whose receptive VMA was closest to but not below 4 years were then selected for inclusion in the experiment. The normal and MLD groups were chosen to match the autistic group as closely as possible on receptive VMA, and the MLD group was also matched to the autistic group on chronological age. The receptive VMA of the children included in the experiment ranged between 4 and 6 years (exactly), except for one child with autism with a receptive VMA of exactly 8 years (her performance did not differ from that of her group).

Details of the participants' chronological age and receptive VMA and the ratio of males to females in each group are shown in Table 1. The gender ratios vary, although there is little difference between the autistic group and the MLD group. In any case, *t* tests comparing the performance of boys and girls for the proportion of logical replies to the problems revealed no significant differences.

Materials. Children's language skills were assessed with the TROG (Bishop, 1982). In the TROG, children select which picture out of four choices best depicts a spoken word or phrase. The test consists of 20 blocks, each of four items, starting with simple nouns, adjectives, and negation, and building up to assess knowledge of complex syntax.

Two sets of eight problems were used in the experimental sessions, Set A and Set B. The problems were based on incongruent modus ponens syllogisms, with the conclusion presented as a question. Half of the problems within each set were correctly answered by affirmation (yes problems) and half by denial (no problems). Within each set of problems, a fixed proportion concerned visual, tactile, or auditory properties. Each problem also had a factual question corresponding to the major premise, to determine whether the content of these premises would be perceived as counterfactual for the individual children. The Appendix lists all of the problems, with factual questions in parentheses.

Procedure. Children were tested individually in their school setting by a familiar experimenter (the two experimenters had previously helped out in the schools or centers). In some cases a teacher with whom a child felt particularly comfortable sat in during the experimental sessions. The children were tested in one preliminary session and two experimental sessions, which were tape-recorded (and all tapes were later transcribed by the first author). The first author collected all of the data except for those of 8 of the 16 children in the autistic group, who were tested by a second experimenter. Initial analyses of performance in the autistic group verified that the identity of the experimenter had no impact upon performance. Each session lasted about 10 to 20 min.

In the preliminary session, all of the children being considered for inclusion in the experiment were given the TROG and then answered the 16 factual questions concerning the content of the problems. Children who answered a question incorrectly were told the correct answer. Children were then selected for inclusion in the experiment according to their receptive VMA and their chronological age (see Participants section).

In each of the two experimental sessions, children were given the appropriate instructions and then presented with the problems verbally, in a random order. The first experimental session took place at least 1 day after the preliminary session. Half of the children within each group received the basic condition in the first session and the instructed condition 2 to 3 weeks later, whereas the remaining children received the conditions in the reverse order. In addition, half of the children in each group and in each order of conditions received Set A in the first session and Set B in the second, whereas the other children received the sets in the reverse order. The mean number of days between sessions did not differ among participant groups: 18.6 (SD = 3.5) in the autistic group, 19.7 (SD = 1.0) in the MLD group, and 19.9 (SD = 1.7) in the normal group.

Instructions, problem presentation, and scoring. At the start of each session, all of the children were given a brief introduction to the problems: "Now we're going to think about some little stories together. Some of the things in the stories may sound a bit funny, but we are going to think about what things would be like if all the things in the stories were true." Children in the basic condition then proceeded to the problems whereas children in the instructed condition received further instructions as follows:

> Let's try one together. Now, I'm going to tell you something that may sound funny, but I want you to think about it; I want you to close your eyes and make a picture in your head of it. All fishes live in trees. So the fishes that you are thinking about, in the picture in your head, where do the fishes live? Are they living in trees? Are they living in water? Good, now, Tot is a fish. Is Tot living in a tree? Is Tot living in water? Good, so now I'm going to tell you some other stories and every time I tell you a story I want you to think about it; I want you to make another picture inside your head of it, just like you did with the fishes.

The worked example required both a "yes" and a "no" response, the order of which was counterbalanced across children. The experimenter gave children feedback on their response to each question, by commenting on their reply and then stating the appropriate response (e.g., "Yes, that's right; the fishes live in trees." or "No, Tot is not living in water.").

The problems were presented in the same manner to all of the children in both conditions. Children were told the major premise of each problem and then asked to repeat it ("What did I just say?") to check that they could recall the information. Any child unable or unwilling to repeat the content of the major premise heard that premise restated once, and the child was given a second attempt at repeating the premise before the rest of the problem was presented. The minor premise of every problem was stated twice directly before the concluding test question. The experimenters accepted all responses in a positive and friendly manner, occasionally saying "fine" or "OK," but without commenting on accuracy, and children were then asked to justify their replies ("Why did you say that?").

Children were scored for the number of factual questions they answered correctly, their accuracy in repeating the major premises of the problems, and the proportion of replies to problems that were logically consistent with the premises. (Recall that a logically inconsistent reply was equivalent to one that was empirically consistent with the real world.) Only problems for which the corresponding factual knowledge question had been answered correctly were considered. This was a precaution against the possibility that some children could answer the problems apparently logically, but actually by appealing to incorrect real-world knowledge. Also, only problems for which children were able to repeat the premises, on either the first or second attempt, were considered. These safeguards were particularly important because accuracy on the factual knowledge questions and the premise repetitions varied across groups.

Children's justifications of their responses were categorized as *premise-oriented* if they showed any evidence of reasoning from the premises as stated (e.g., "Because you said it was black"; "Because they are spotty in the story") or as *knowledge-oriented* if they only referred to factual knowledge or experience (e.g., "Because pigs aren't green"; "Because I know the grass should be green"). In addition, some children offered no justifications or justifications that were irrelevant or ambiguous. Analysis of children's justifications was aimed at comparing the extent to which children referred to the premises as stated rather than to their empirical knowledge in each session. Thus, the proportion of each child's premise- and knowledge-oriented justifications that were premise-oriented was calculated.

Results

The results are described in five sections: the accuracy with which children answered the factual questions and repeated the major premises, the frequency and distribution of logically consistent replies to the problems, individuals' performance on the problems, the pattern of children's justifications, and the relation between replies to the problems and justifications.

Performance on the factual questions and premise repetitions. For each set of problems, the normal group answered at least 98% of the factual knowledge questions correctly, the MLD group answered at least 95% correctly, and the autistic group answered at least 86% correctly. *T* tests comparing these figures revealed that the autistic group was less accurate than the normal group, $t(62) = 2.88$, $p < .05$, and the MLD group, $t(62) = 1.91$, $p < .05$. The normal and MLD groups also differed in accuracy, $t(62) = 1.74$, $p < .05$.

During presentation of the problems, children were asked to repeat the major premise of each problem. The percentage of premises repeated incorrectly on the first attempt was 19% in the autistic group, 6% in the MLD group, and 4% in the normal group. Analysis with *t* tests revealed that the autistic group gave more incorrect repetitions than both the normal group, $t(30) = 3.06$, $p < .05$, and the MLD group, $t(30) = 2.63$, $p < .05$, which did not differ from each other. The percentage of premise checks that were repeated incorrectly on both attempts was also compared across the groups and the same pattern was found: The autistic group was incorrect more often than the MLD group (13% as compared with 1%), $t(30) = 2.77$, $p < .05$, and the normal group (0%), $t(30) = 2.48$, $p < .05$; performance did not differ between the MLD and normal groups.

In sum, although performance by all three groups was quite accurate in absolute terms, the autistic group was less accurate than the other two groups on factual knowledge questions and on repetition of the major premise. In addition, the MLD group was less accurate than the normal group on the factual knowledge questions.

Replies to the problems. Table 2 shows the mean proportion of logical replies to the problems for which factual knowledge was correct and the major premise had been repeated, shown by participant group, condition, and session in which the condition was delivered. Because the data were proportional, an arcsine transformation was applied to the square root of each datum to normalize the distribution for analysis. A five-way analysis of variance (ANOVA) was per-

TABLE 2
Mean Proportion of Logical Replies for Which Factual Knowledge Was Correct and the Major Premise Was Repeated, Shown by Group, Condition, and Session

	Basic			Instructed		
Group	Session 1	Session 2	Mean	Session 1	Session 2	Mean
Normal	.16 (.30)	.72 (.30)	.44 (.41)	.67 (.33)	.67 (.34)	.67 (.32)
MLD[a]	.22 (.17)	.58 (.28)	.40 (.29)	.60 (.32)	.48 (.36)	.54 (.34)
Autistic	.36 (.17)	.36 (.27)	.36 (.22)	.37 (.20)	.48 (.26)	.43 (.23)

Note. Standard deviations are in parentheses.
[a] MLD = moderate learning disability.

formed on these transformed data with between factors of participant group (three levels: autistic, MLD, and normal), order of conditions (two levels: basic then instructed, instructed then basic), and order of problem set (two levels: A then B, B then A), and within factors of condition (two levels: basic, instructed) and problem type (two levels: yes problem, no problem). The analysis produced main effects of condition, $F(1, 36) = 8.18$, $p < .05$, order of condition, $F(1, 36) = 5.33$, $p < .05$, and problem type, $F(1, 36) = 7.58$, $p < .05$. There was an interaction between order of conditions and condition, $F(1, 36) = 10.78$, $p < .05$, and an interaction between participant group and problem type, $F(2, 36) = 3.27$, $p < .05$. Inspection of the means suggests that the impact of instruction is strongest in the normal group, intermediate in the MLD group, and weakest in the autistic group. However, the interaction between participant group and condition did not reach significance, $F(2, 36) = 1.38$, *ns*.

Figure 1 shows the interaction between order of conditions and condition. This interaction was investigated by simple effects post hoc tests. When the basic condition preceded the instructed condition there were more logical replies in the instructed condition (untransformed mean, .581) than in the basic condition (untransformed mean, .160), $F(1, 36) = 18.87$, $p < .05$. When the instructed condition preceded the basic condition there was equivalently high logical performance in the instructed condition (untransformed mean, .567) and the subsequent basic condition (untransformed mean, .598). The instructed condition yielded similar performance, whether it was received first or second, whereas there were fewer logical replies in the basic condition when it was received first than when it was received second, following the instructed condition, $F(1, 36) = 17.72$, $p < .05$. Thus, the benefits of instruction observed in the first session were still apparent in the second session, even though previously instructed participants were given only a basic introduction in that second session.

Figure 2 shows the interaction between participant group and problem type. Inspection of the figure suggests that children with autism gave fewer logical replies to no problems than to yes problems. Simple effects tests confirmed this.

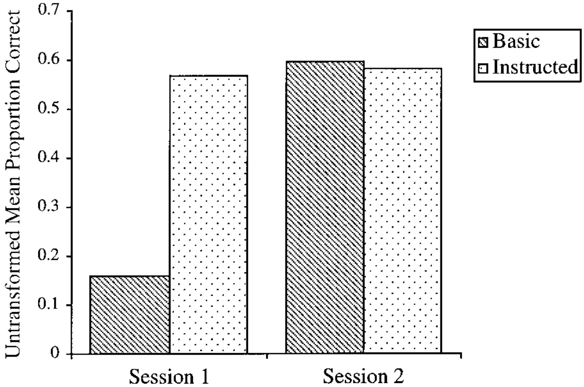

FIG. 1. Proportion of logical replies to problems for which factual knowledge and major premise repetition were correct, shown by condition and session.

Performance differed among the participant groups for the no problems, $F(2, 36) = 4.70$, $p < .05$, but not for the yes problems. The proportion of logical replies in the normal group did not differ between yes problems (untransformed mean, 0.65) and no problems (untransformed mean, 0.52). Similarly, the proportion of logical replies in the MLD group did not differ between yes problems (untransformed mean, 0.48) and no problems (untransformed mean, 0.45). However, there was a higher proportion of logical replies following yes problems (untransformed mean, 0.64) than following no problems (untransformed mean, 0.13) in the autistic group, $F(1, 36) = 13.29$, $p < .05$. Inspection of performance on individual problems, and also on the problems split into whether they were based on visual, auditory, or tactile properties, revealed no apparent

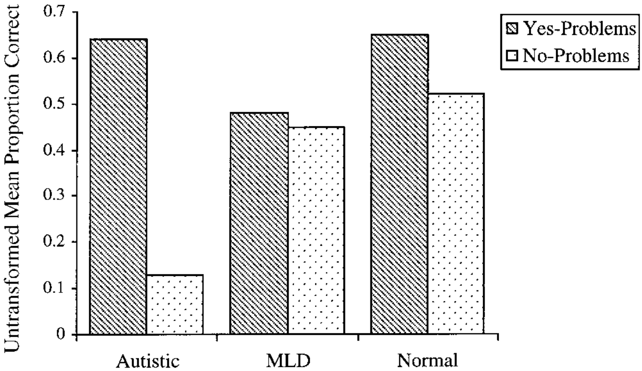

FIG. 2. Proportion of logical replies to problems for which factual knowledge and major premise repetition were correct, shown by participant group and problem type.

TABLE 3
Classification of Performance as Mixed, Logical, or Empirical in Sessions 1 and 2, Shown by Group and Order of Conditions

		Autistic		MLD[a]		Normal	
Session 1	Session 2	B–I	I–B	B–I	I–B	B–I	I–B
Mixed	Mixed	7	6	4	4	2	3
Mixed	Empirical	0	0	1	0	0	0
Empirical	Mixed	1	0	1	0	2	1
Empirical	Empirical	0	1	0	0	1	0
Mixed	Logical	0	1	0	1	0	1
Logical	Mixed	0	0	0	2	0	0
Logical	Logical	0	0	0	1	1	3
Empirical	Logical	0	0	2	0	2	0
Logical	Empirical	0	0	0	0	0	0

Note. B–I = basic then instructed condition; I–B = instructed then basic condition.
[a] MLD = moderate learning disability.

variation in performance dependent on problem features other than response required.

The above five-way ANOVA was repeated with other data sets (the same data before transformation and a data set considering performance on all of the problems, both before and after transformation). Each analysis produced results consistent with those of the analysis detailed here: Children who received basic instructions in the first session gave fewer logical replies than in the second session, when they received further instruction. Children who received further instruction in the first session gave an equally high number of logical replies in that session and in the second session, when they received only basic instructions. All analyses also revealed a bias toward saying "yes" in the autistic group only.

Individual performances. The performance of individual children within a session was assigned to one of three categories. Performance was classified as "logical" or "empirical" if at least seven of eight problems were answered correctly or incorrectly (i.e., significant by the binomial distribution, $p < .05$, assuming that "yes" and "no" responses were equally likely). When fewer problems were considered, the comparison to chance was adjusted accordingly (i.e., if seven, six, or five problems were considered, performance differed from chance if all of the problems were answered the same way; performance could not differ from chance if fewer than five problems were considered). Children whose performance did not differ from chance were classified as "mixed."

The classification of individuals' performance in each session as mixed, logical, or empirical is shown in Table 3, by group, session, and order of conditions. Inspection of Table 3 confirms that within each of the four combinations of session and condition the relative proportion of children classified as empirical versus logical varies in a way that is consistent with the results of the ANOVA described in the previous section. When basic instruction was given in Session 1, only 1 out of 10 children (10%) responded logically as opposed to empirically. However, when further instruction was given in Session 1 or in Session 2, the comparable proportions were 6 out of 8 children (75%) and 5 out of 7 children (71%). Finally, when only basic instruction was given in Session 2 (having been preceded by further instruction in Session 1), the comparable proportion was 7 out of 8 children (87.5%). Thus, empirical classifications outweighed logical classifications only for Session 1 with basic instruction.

Further inspection of Table 3 reveals that the groups differed in the frequency with which they responded in either a logical or an empirical fashion (rather than with a mixed pattern). Thus, in the autistic group, a logical or an empirical performance was produced in both sessions by 1 child, in one session by 2 children, and in neither session by 13 children. Comparable figures in the MLD group were 3, 5, and 8 children, respectively, and in the normal group, 7, 4, and 5 children, respectively. A Kolmogorov–Smirnov test confirmed that the children in the autistic group were less likely to be classified as either logical or empirical than children in the normal group, K_D $(N = 16) = 8$, $p < .05$, although the MLD group did not differ significantly from either of the other two groups.

In sum, there was a clear effect of instruction that persisted across sessions. Analysis of individual patterns of performance confirmed this effect; children classified as empirical outnumbered children classified as logical only when basic instruction was given in the first session. Although the overall effect of instruction did not vary across the three groups, important group effects were found. The autistic group, but neither of the other two groups, showed a significant bias toward answering “yes” rather than “no.” In addition, most children in the autistic group failed to display either a systematically logical pattern or a systematically empirical pattern in either session.

Justifications. Children’s justifications were categorized by both experimenters as being premise-oriented, knowledge-oriented, or arbitrary. There was 92% agreement between the experimenters, and discrepant judgments were discussed and agreed upon. Table 4 shows the proportion of premise- and knowledge-oriented justifications that were premise-oriented. This index of the extent to which children favored premise- rather than knowledge-oriented justifications is shown as a function of group, condition, and session in which the condition was delivered. A three-way ANOVA, with between factors of group and order of conditions and a within factor of condition, was performed on these data following an arcsine transformation of their square roots. (The seven participants who gave only arbitrary justifications throughout a session were included, with the corresponding datum replaced with a zero.) The analysis produced a main effect of order of condition, $F(1, 42) = 9.53$, $p < .05$, and an interaction between condition and order of condition, $F(1, 42) = 4.83$, $p < .05$.

TABLE 4

Mean Proportion of Premise- and Knowledge-Oriented Justifications and the Bias toward Premise-Oriented Justifications for Problems for Which Factual Knowledge and Premise Repetition Were Correct, Shown by Group, Condition, and Session

				Bias to premise-oriented[a]		
Group	Condition	Premise-oriented	Knowledge-oriented	Session 1	Session 2	Mean
Normal	Basic	.34 (.39)	.38 (.35)	.11 (.31)	.52 (.47)	.31 (.44)
	Instructed	.45 (.39)	.28 (.28)	.57 (.40)	.48 (.49)	.53 (.44)
MLD[b]	Basic	.17 (.24)	.37 (.35)	.05 (.10)	.46 (.40)	.25 (.35)
	Instructed	.34 (.39)	.27 (.33)	.60 (.39)	.27 (.45)	.43 (.44)
Autistic	Basic	.18 (.19)	.47 (.33)	.18 (.24)	.40 (.35)	.29 (.31)
	Instructed	.21 (.28)	.27 (.23)	.34 (.35)	.32 (.37)	.33 (.35)

Note. Standard deviations are in parentheses.

[a] Bias to premise-oriented = mean proportion of premise-oriented and knowledge-oriented justifications that were premise-oriented calculated by participant.

[b] MLD = moderate learning disability.

The interaction between condition and order of condition is illustrated in Fig. 3. Inspection of the figure shows that the pattern of results was similar to that obtained for the proportion of logical replies to the problems (see Fig. 1). Analysis by simple effects tests confirmed that there was an increased proportion of premise-oriented justifications in the instructed condition (untransformed mean, .306), as compared with the basic condition (untransformed mean, .053), when the basic condition preceded the instructed condition, $F(1, 42) = 7.69$, $p < .05$. When the instructed condition preceded the basic condition, there was

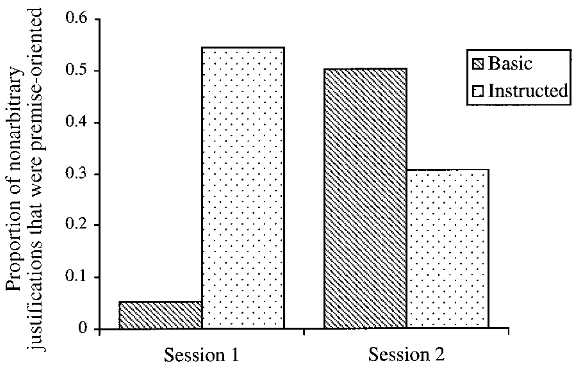

FIG. 3. The interaction between order of condition and condition for proportion of premise- and knowledge-oriented justifications that were premise-oriented (considering problems for which factual knowledge and major premise repetition were correct).

a high proportion of premise-oriented justifications in that condition (untransformed mean, .501), which did not diminish in the later basic condition (untransformed mean, .544). The instructed condition yielded similar performance, whether it was received first or second, whereas there were fewer premise-oriented justifications in the basic condition when it was received first than when it was received second, following the instructed condition, $F(1, 42) = 19.72$, $p < .05$. In sum, the beneficial effects of instruction on the pattern of justifications mirrored that observed for logical replies. The benefits of instruction were observed in the first session, and persisted into the second session, even though previously instructed participants were given only a basic introduction in that second session.

Although the above analyses revealed no effect of group, it is noteworthy that 41 of the 42 premise-oriented justifications given by the children with autism simply restated information from the major premise rather than elaborating, for instance, that they were thinking about the story in their head or that the experimenter provided them with the information (compared with 42 of 62 for the MLD group and 75 of 100 for the normal group). In fact, only 1 child in the autistic group gave an elaborate premise-oriented justification, compared with 7 in the normal group ($p < .05$, Fisher Exact Probability Test) and 6 in the MLD group ($p < .10$, Fisher Exact Probability Test). There was no difference between the normal and MLD groups.

In summary, analyses of the justifications produced two important results. First, the tendency to give premise- rather than knowledge-oriented justifications mirrored the pattern reported with respect to the number of logical replies: Children gave few premise-oriented justifications (and few logical replies) only when given basic instructions in an initial session. Second, children in the autistic group almost always confined their premise-oriented justifications to unadorned repetition of the information in the premises, unlike children in the normal and MLD groups.

Relation between replies to the problem and justifications. Hitherto, replies and justifications have been analyzed separately. In this section, the relation between logical replies and premise-oriented justifications and between empirical replies and knowledge-oriented justifications will be examined. All of the problems were considered in these comparisons, making a strong test of the strength of these associations. A paired t test was used to compare the proportion of justifications that were premise-oriented following logical as compared with empirical replies for each child. Similar comparisons were made for the knowledge-oriented and arbitrary justifications. The two children who gave only logical or only empirical replies to all 16 problems were included, with the proportions which would have had a denominator of zero, replaced with a zero. Three further analyses excluding these children produced results consistent with those reported here. Children were significantly more likely to give a premise-oriented justification following a logical reply than an empirical reply: 94% of premise-oriented justifications followed logical replies, and only 6% followed empirical replies, $t(47) = 9.41$, $p < .05$. Conversely, significantly more knowledge-oriented justifications (97%) followed empirical replies than followed logical replies (3%), $t(47) = 13.56$, $p < .05$. Arbitrary justifications (i.e., justifications that could not be placed into either of these categories) were equally likely to follow logical (53%) and empirical (47%) replies.

DISCUSSION

The results of this experiment add to accumulating evidence that young children can set aside an empirical bias and reason logically from counterfactual premises, particularly following instructions to use mental imagery. In this discussion, we first consider the variation in performance across the three participant groups and then the persistent impact of instruction. In considering each of these two issues, we first review our findings, evaluate existing explanations for those findings, and then propose our own interpretation.

There were several differences in performance among the different participant groups. First, children with autism were less accurate than the other two groups in answering the factual knowledge questions and repeating the major premises of the problems. This may have occurred because the groups were matched only for receptive verbal abilities—groups may have varied in expressive language. Second, although there were no differences across the groups in the number of logical replies or premise-oriented justifications, there were group differences in the nature of both of these responses: Children with autism gave fewer "no" responses than the other two groups and in offering premise-oriented justifications they were more likely to simply restate information from the premises than the 4-year-olds and to some extent the children with learning disabilities. Third, instead of answering a set of problems consistently in either a logical or an empirical manner, most children with autism displayed an unsystematic mixture of empirical and logical responses in each of the two sessions.

In contrast to the findings of Scott et al. (1999), children in the autistic group gave no more logical replies than children in the MLD and normal groups, irrespective of condition. It is possible that the children with autism in the two experiments differed in the nature of autism presented (autism is a highly heterogeneous disorder). However, aspects of the performance of the autistic group point to a different explanation. In the Introduction, we noted that the apparently logical performance of children with autism in the basic condition reported in Scott et al. (1999) might have resulted from a yes bias, "yes" being the correct, logical reply for all problems in that study. The experiment reported here revealed a yes bias in the autistic group and only in this group. Such an alogical strategy may indicate confusion and reflect an "overaffirmation tendency" (Scoville & Gordon, 1980) or the positive mood (i.e., lack of negation) of the problems (Woodworth & Sells, 1935). However, Scott et al. (1999) maintain that the children with autism were answering logically because they went on to justify their "yes" replies by referring to the premises. Nevertheless, children with autism may have simply echoed the premises with little insight that they were appropriately justifying logical replies. This interpretation is consistent with a second feature of the performance of children with autism in the present study. Only 1 of their 42 premise-oriented justifications went beyond information in the premises, compared with 20 of 62 in the MLD group and 25 of 100 in the normal group (in which children mentioned, for example, that the experimenter had provided them with the information or that they were thinking about the story).

A possible explanation for the failure of children with autism to respond logically is that they could not conceive of the counterfactual states introduced in the major premise of each problem or that they could not go on to draw inferences about such counterfactual states. This interpretation is consistent with the traditional claim that autism is associated with an impairment in make-believe. We are not convinced by this argument for several reasons. First, contemporary research has cast doubt on the depth of the impairment in pretense. Although children with autism may be less motivated to engage in pretense (Lewis & Boucher, 1988), or less able to generate pretend activities (Jarrold, Boucher, & Smith, 1996), they perform well in instructed pretense (Jarrold, Boucher, & Smith, 1994; Lewis & Boucher, 1988). Second, a further study conducted with the children included in this experiment showed that there were no differences among the groups in their ability to conceptualize "impossible" entities, as measured by their accuracy in identifying or completing drawings depicting "impossible" versus "real" entities (Leevers & Harris, 1998), even when the "impossible" entities were deliberately based on problems used in the present experiment. Third, Scott et al. (1999) found that children with autism reported that they were able to make a mental image of a flying pig even if they misunderstood its status (i.e., claimed that it was real or that the experimenter could see it). Fourth, if children with autism were able to reason logically, but unable to imagine counterfactual premises, then they would be expected to answer empirically. This was almost never the case. Analysis of individual performances reveals that only two of the children with autism reasoned empirically in one or both sessions. Finally, there is evidence that autistic children are able not only to imagine a nonexistent state of affairs but to draw inferences about the outcome of pretend transformations (Kavanaugh & Harris, 1994).

We propose instead that the pragmatic difficulties that children with autism display in conversation are a key factor in explaining their performance. More specifically, we propose that the children with autism failed to appreciate that the experimenter intended them to accept and reason about the false proposition presented at the beginning of each problem. Normally developing preschoolers appear to need minimal prompting to understand the experimenter's intention that they accept such premises as a basis for reasoning. For instance, simply presenting the problems in a "make-believe" intonation boosts logical performance (Dias & Harris, 1990). In contrast, as noted in the Introduction, children with autism have persistent difficulties in understanding a speaker's intention (Frith, 1989; Happé, 1994; Howlin, 1997). For example, Happé (1993) has shown that relatively unimpaired individuals with autism have difficulty grasping nonliteral utterances in which a person's implicit communicative intention must be taken into account, such as metaphors (in which the speaker intends to communicate a likeness but does not explicitly state this) and irony (in which the speaker utters a statement but intends to convey its opposite). To handle the incongruent premises used in the present experiment, children needed to recognize the experimenter's intention that they accept the premises as a basis for reasoning despite their literal falsehood. We suggest that children with autism, having failed to recognize that intention, resorted either to random responding or to a simple response bias. This proposal is consistent with all three of the distinctive features of their behavior in the present experiment: their lack of systematic responding, be it empirical or logical; their perseverative strategy of saying "yes" in reply to the test question; and their "justification" of such replies by simple repetition of the premises without further elaboration.

Our proposal implies that children with autism should be able to reason from counterfactual propositions if their interlocutor's intention were made fully transparent. Consistent with that expectation, they do respond appropriately to explicit counterfactual questions, such as "If Mummy hadn't made the cake, where would the chocolate be?" (Peterson & Bowler, 1996) and they can imagine counterfactual antecedents and consequences for causal episodes (e.g., suggesting a way in which a story character could have prevented getting her socks muddy when playing in the garden, for instance, by wearing boots; Hadwin & Bruins, 1998). In addition, children with autism are not impaired in other aspects of reasoning, such as analogical reasoning or transitive inference (Scott & Baron-Cohen, 1996). Accordingly, we predict that children with autism will reason from counterfactual premises that are explicitly conditional (e.g., "If all snow were black . . .") even if they do not reason from the counterfactual assertions included in the present study. Conditional premises that include "if" and the subjunctive thereby mark the need to set aside empirical knowledge and to temporarily accept a false proposition. It is not unprecedented for such a minimal change of wording to have a dramatic effect on performance. As noted above, Happé (1993) found that individuals with autism have great difficulty in understanding metaphors, in which the intention to draw a likeness is implicit (e.g., "Michael was so cold. His nose was really an icicle.") but they have no difficulty in understanding similes where the intention to draw a likeness is made explicit (e.g., "The dog was so wet. It was *like* a walking puddle.").

We now turn to the other main finding in this experiment: the robust interaction between order of conditions and condition. The children who received the basic condition followed by the instructed condition gave many more logical replies in the instructed condition than in the preceding basic condition. The children who received the instructed condition followed by the basic condition gave many logical replies in the instructed condition (equivalent to those given by the children receiving instruction in the second session). However, these children gave no fewer logical replies in the ensuing basic condition than in the first instructed condition. A parallel pattern emerged when the performance of individual children was classified within each session. Empirical classifications outnumbered logical classifications only for the first session with basic instruction. Similarly, the bias toward premise- rather than knowledge-oriented justifications was especially weak in that same session.

Taken together, the findings for logical replies and for justifications imply not only that further instruction increases logical responding, but also that the effect of that further instruction persists for at least 2 to 3 weeks—the length of the break between sessions. These data support and extend earlier findings of weeklong effects of instruction (Leevers & Harris, 1999). Moreover, they show that the empirical approach induced among children who received the basic condition in the initial session is not a long-term strategy. Having previously answered the problems empirically did not lessen the benefits of later further instruction. Thus, the long-term effects of instruction are not simply the result of children remembering the mode of responding used in the first session and generalizing it to the second session. Transfer across sessions occurs only for children given instructions promoting logical reasoning in the first session but not for children given only a basic introduction to the problems.

As noted in the Introduction, the beneficial effect of instruction has been attributed to the induction of a make-believe stance or a cognitive filter. However, we believe that the improvement in performance over a period of 2 to 3 weeks casts doubt on these two proposals because it is unlikely that such inductions would persist so long. There are both conceptual and empirical grounds to suppose that the special mode of processing associated with a make-believe stance is tied to a given episode of make-believe, and is not an enduring stance (Harris & Kavanaugh, 1993; Leslie, 1987). Moreover, there are several other findings that cast doubt on these proposals. First, Markovits (1993, 1995) predicts that individual children in the uninstructed condition will perform around chance levels. More specifically, he argues that when children are presented with a counterfactual premise (e.g., "All snow is black.") that conflicts with their own factual knowledge (i.e., "All snow is white.") they will incorporate both pieces of information into their representation of the problem, and refer to each approximately half the time. Yet three quarters of the uninstructed children in the normal group (i.e., children answering in the basic condition in Session 1) performed in either a predominantly empirical or a predominantly logical fashion. Second, the induction of either a make-believe attitude or a cognitive filter would not be expected to affect performance on material for which there is no relevant empirical knowledge, because the assumed benefit of such inductions is to prevent the intrusion of empirical knowledge inconsistent with the major premise. However, Dias and Harris (1988, Experiment 1) report that make-believe instructions improved syllogistic reasoning not just with counterfactual premises (e.g., “All cats bark.”) but also with unfamiliar premises (e.g., “All hyenas laugh.”). Similarly, Leevers and Harris (1999) found that further instruction improved reasoning with invented premises (e.g., “All merds are square.”). Presumably it is difficult to construct a mental image for such invented premises, further suggesting that the use of imagery may not be a necessary element in improved performance. Finally, Leevers and Harris (1999) demonstrated that instructions containing no prompt to use imagery or the imagination, but a simple request to “think about” the major premises, were as effective in encouraging logical performance as instructions explicitly directing children to use imagery.

An alternative explanation of the finding that children persisted with logical replies is that the experimenters failed to maintain a consistent manner toward children’s responses. For example, they may have provided unintentional reinforcement for logically accurate as opposed to empirical replies. On the other hand, this account provides only a partial explanation of the findings. It might explain why children persisted with logical replies either within or across sessions. However, it offers no explanation for the differential performance of children in the basic as compared to the further instruction condition in the first session nor for the improvement across sessions among children given basic instructions and then further instructions. Nonetheless, this alternative explanation points to the desirability in future research of recording experimenter feedback and checking its consistency across accurate and inaccurate replies.

We believe that a more plausible interpretation of the findings can again be found by considering the pragmatics of the exchange between the experimenter and the child. In the absence of further instruction, children are not likely to understand the experimenter’s intention that a false premise should be accepted as a basis for reasoning. Thus, children discount such premises and give empirical replies. In the extreme, children are confused by the reasoning situation per se, and may perform around chance (as was evident in some of the children in each group, particularly the autistic group). Further instruction indicates that the major premise is relevant and important even though it is false (Harris & Leevers, 2000). Such instruction may indicate the relevance of the major premise directly, for example, by asking children to “think about” the premise, or indirectly, for example, by asking children to construct an image around the premise. Alternatively, a story intonation or a reference to a far-off planet introduces a conversational setting in which false propositions can be regarded as an acceptable starting point for later information. This proposal is consistent with the finding that further instruction improves syllogistic reasoning not just on counterfactual premises, but also on unfamiliar or invented premises that do not conflict with real-world knowledge. Children may be reluctant to accept such novel material as a starting point for reasoning unless the experimenter indicates its relevance.

We further suggest that children who correctly interpret the pragmatics of an otherwise anomalous interchange typically reapply that interpretation in later sessions. In future research, it will be informative to vary the nature of the major premise both in the initial session and from one session to the next. A demonstration that improved performance on counterfactual premises generalizes to unfamiliar premises, and vice versa, would strengthen the current emphasis on children's understanding of what the experimenter intends.

In conclusion, the results of the present study confirm earlier claims regarding the effects of instruction on children's reasoning. Although normal children often approach syllogisms with an empirical bias, and perform poorly when given premises that run counter to their empirical knowledge, that bias can be overcome if they are instructed to imagine the situation described in such premises. However, the results also cast doubt on the standard interpretation of such effects of instruction. Because instruction led to persistent benefits over a 2- to 3-week period, it is unlikely that it induces a make-believe stance or a cognitive filter. Accordingly, we have explored a different interpretation, one that focuses on the conversational exchange between the experimenter and the child. We propose that an understanding of the experimenter's intention in asserting a false proposition is an important factor in determining children's performance. Especially among normal preschoolers, further instruction serves to clarify the experimenter's intention, namely that incongruent premises be accepted as a basis for reasoning. In contrast, the pattern of performance by children with autism is consistent with the hypothesis that having failed to understand the experimenter's intention, they resort to random responding or a simple response bias. For the time being our interpretation should be regarded as a working proposal rather than a definitive account. Nonetheless, research in which the experimenter's intention is made more or less transparent—a manipulation that can be achieved by apparently minor changes of wording—offers a way to assess its merits.

APPENDIX

The Problems, with Corresponding Factual Questions in Parentheses

Set A, yes problems	Set B, yes problems
(What have zebras got on their backs?) All zebras have spots on their backs. Alex is a zebra. Is Alex spotty?	(How does ice feel to your fingers?) All ice feels hot. Jill has her hand in some ice. Does Jill's hand feel hot?
(How does a river feel to your fingers?) All rivers feel dry. Stan has his hand in a river. Does Stan's hand feel dry?	(What noise do dogs make?) All dogs meow. Ben is a dog. Does Ben meow?

(What noise do cows make?)
All cows quack.
Susie is a cow.
Does Susie quack?

(What color is grass?)
All grass is blue.
The garden is covered in grass.
Is the garden blue?

(What color are pigs?)
All pigs are green.
Percy is a pig.
Is Percy green?

(How do stones feel to your fingers?)
All stones feel soft.
The playground is covered in stones.
Does the playground feel soft?

Set A, no problems

(How do hedgehogs feel to your fingers?)
All hedgehogs feel soft.
Harry is a hedgehog.
Does Harry feel prickly?

(What color are swans?)
All swans are red.
Slinky is a swan.
Is Slinky white?

(What noise do cats make?)
All cats bark.
George is a cat.
Does George meow?

(How does fire feel to your fingers?)
All fire feels cold.
Lily has her hand in the fire.
Does Lily's hand feel hot?

Set B, no problems

(What color is snow?)
All snow is black.
Len is a snowman made of snow.
Is Len white?

(What noise do ducks make?)
All ducks moo.
Ralph is a duck.
Does Ralph quack?

(What have ladybirds got on their backs?)
All ladybirds have stripes on their backs.
Daisy is a ladybird.
Is Daisy spotty?

(How does water feel to your fingers?)
All water feels dry.
Ann has her hand in some water.
Does Ann's hand feel wet?

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