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Teaching and preschoolers' ability to infer knowledge from mistakes

Samuel Ronfard [a,*], Kathleen H. Corriveau [b]

[a] Graduate School of Education, Harvard University, Cambridge, MA 02138, USA
[b] School of Education, Boston University, Boston, MA 02215, USA

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ABSTRACT

For instruction to be effective, teachers must adjust the way they teach to match what learners know. We asked whether children's ability to infer what someone knows based on his or her mistakes develops alongside their teaching—children's use of more explicit teaching strategies and their ability to tailor how much information to provide in response to their pupils' mistakes. Preschoolers ($N = 48$) were taught a simple game and were then introduced to four puppets: one puppet who played the game perfectly, two puppets who each made one mistake, and one puppet who made two mistakes. After watching each puppet play individually, children were asked to rate the puppet's understanding of the game and then were invited to teach the puppet. Children's ability to monitor the relative accuracy of the puppets—the ability to make nuanced judgments about what each puppet understood based on each puppet's unique mistakes—improved with age. Moreover, older children were more explicit and more precise teachers than younger children. They more often contrasted the learners' mistakes with what should be done and more often provided instructions that directly addressed the puppets' unique mistakes. Thus, between 3 and 5 years of age, developments in children's ability to infer knowledge from mistakes parallel developments both in the strategies children use to teach and in the amount of information they teach in response to mistakes.

* Corresponding author.
E-mail address: sar798@mail.harvard.edu (S. Ronfard).

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Introduction

For instruction to be effective, teachers must select evidence that will help a naive learner understand a new concept (Gweon, Chu, & Schulz, 2014; Rhodes, Bonawitz, Shafto, Chen, & Caglar, 2015; Rhodes, Gelman, & Brickman, 2010) *and* adjust their teaching as the learner's understanding develops. This ability to provide targeted instruction by responding to specific mistakes appears to have played a critical role in the advancement of human history. Existing research suggests that teaching may naturally develop in humans (e.g., Strauss, Ziv, & Stein, 2002) and that humans are predisposed to learn from teaching (Csibra & Gergely, 2009). Specifically, teaching improves the transmission of complex skills such as the making of stone tools (Morgan et al., 2015), and learners who receive verbal instructions are able to build more robust tools as compared with learners who engage in imitation or emulation (Zwirner & Thornton, 2015). Surprisingly, given the importance of teaching in the advancement of innovation, the cognitive abilities supporting human teaching have been relatively understudied as compared with human learning (Kline, 2015; Strauss et al., 2002).

In the current study, we attempted to highlight one such ability required for high-quality instruction: the ability to track what learners understand (e.g., Kruger & Tomasello, 1996; Wood, Wood, Ainsworth, & O'Malley, 1995). One method for evaluating a learner's knowledge is to analyze the learner's specific mistakes, allowing for specialized instruction explicitly targeting areas of confusion. Thus, the first goal of our study was to examine the development of children's ability to infer how much someone knows based on his or her mistakes.

Although no research has focused explicitly on children's ability to use a learner's mistakes to make an inference about the learner's knowledge, the findings from two distinct bodies of research suggest that young children's ability to use mistakes to infer knowledge may develop across the preschool years. First, a large body of research has focused on children's ability to use a teacher's past accuracy to make an inference about the teacher's future credibility (e.g., Harris, 2012; Harris & Corriveau, 2011). These data indicate that children are surprisingly adept at making inferences based on limited behavioral evidence, although the type of inference children make changes over the preschool years. For example, 3-year-olds attend to a teacher's inaccuracies only, avoiding learning from an interlocutor after the teacher makes as little as one mistake (Corriveau, Meints, & Harris, 2009; Pasquini, Corriveau, Koenig, & Harris, 2007). By contrast, 4-year-olds attend to a teacher's relative history of accuracy, giving credit to a teacher who has been mostly accurate over a teacher who has been mostly inaccurate.

Second, although the standard unexpected contents and change of location false belief tasks were intended to measure children's ability to recognize that others' (false) beliefs might differ from their own (e.g., Wellman & Liu, 2004), to succeed on the task, children must recognize a mistaken belief in others. Data from a meta-analysis of the false belief task indicates that children's ability to recognize a mistaken belief in others develops across the preschool years, with 4-year-olds displaying enhanced performance as compared with 3-year-olds (Wellman & Liu, 2004). This development is associated with children's understanding that teaching is likely to occur not only when there is a gap in knowledge between the teacher and the learner but also when the teacher thinks that such a gap exists (Ziv & Frye, 2004). Based on these two bodies of literature, we anticipated that children's ability to make inferences about how much someone knows based on his or her mistakes would develop across the preschool years (see Ziv & Frye, 2004; Ziv, Solomon, Strauss, & Frye, 2016).

A second goal of this study was to investigate developments in children's teaching. Specifically, we explored developments in the strategies children used when teaching as well as developments in children's ability to tailor their instruction to a pupil's specific mistake. Children's ability to adjust their instruction based on a pupil's understanding (i.e., of game rules) develops in parallel to their ability to attribute mental states and to track their teachers' inaccuracies. When presented with a naive learner, older preschoolers, but not younger preschoolers, use more explicit and verbal teaching strategies such as directing the learner's attention and referencing the learner's prior behavior (Davis-Unger & Carlson, 2008; Recchia, Howe, & Alexander, 2008; Strauss & Ziv, 2012; Strauss et al., 2002; Wood et al., 1995). These more explicit teaching strategies suggest that older children are better able to scaffold learning for their pupils because they are better able to track learners' developing understanding. Indeed, Wood and colleagues (1995) found that only 24% of 5-year-olds, but 68% of 7-year-olds, engaged in contingent teaching, adjusting the amount of support they gave their pupil based on the pupil's ongoing performance (i.e., providing more support if the learner struggled and less support if the learner was successful). Taken together, these studies indicate that older children are more responsive teachers in that they are better able to change the way they teach (i.e., modify the type of teaching strategies they use and the number of strategies they use) in response to their pupils' performance. However, to date no study has examined the development of children's ability to directly address a pupil's mistakes. That is, we know that with age children change *how* they teach in response to mistakes, but we do not know whether younger and older children differ in the *amount of information* they provide in response to mistakes. Some research suggests that 5- to 7-year-olds can adjust the amount of information taught to a learner based on whether their pupil had some prior knowledge, rather than none, about how a toy worked (Gweon, Shafto, & Schulz, 2014). Note, however, that in Gweon and colleagues' (2014) study children did not need to infer the learner's knowledge from the learner's behavior. Thus, an open question is whether younger and older children can make such adjustments *in real time* based on the *mistakes* of their pupil.

Unlike previous studies where the to-be-taught learner was explicitly labeled as one who does not know the rules of the game, we modified the knowledge state of the learner by varying the learner's behavior and asked how children used such behavior to make inferences about the learner's ability to play the game. We also asked whether children would modify the information they provided to the learner based on the learner's unique mistake. This design allowed us to observe the development of these two capacities simultaneously.

Children were taught a simple game; red, but not black, pieces needed to be placed inside a red square. We devised this simple two-rule game to minimize task demands and ensure that the youngest children in our study (3-year-olds) would be able to quickly learn the game and to remember the rules, thereby allowing us to focus specifically on children's teaching behavior. Next, children were introduced to four puppets, each of whom played the game individually. One puppet played the game without error (expert), whereas the other three puppets made errors: two puppets made a single, but different, mistake (correct piece, wrong location; wrong piece, correct location), and the other puppet made two mistakes (wrong piece, wrong location).

Immediately after each puppet played the game, children were asked to select whether the puppet knew nothing, some things, or everything about the game based on their observation of the puppet and were subsequently asked to teach the puppet. This design allowed us to assess children's ability to infer the amount each puppet understood about the game, based on the puppet's mistakes, as well as to observe children's ability to adjust their teaching based on the puppet's knowledge. Specifically, we could code whether, in the case where the puppet made only one mistake, children's teaching directly addressed the puppet's mistake or was over-informative (i.e., provided information about both mistakes).

We anticipated that children's ability to track a learner's mistakes might follow the same developmental progression as their ability to track the accuracy of their teachers (Pasquini et al., 2007). That is, younger children would judge learners in an all-or-none fashion, grouping together all learners who had made mistakes without differentiating between the amount of mistakes, whereas older children would attend to the relative amount of mistakes, assuming that a learner who had made one mistake was more knowledgeable than a learner who had made two mistakes.

We also expected to replicate the well-established pattern that older children would engage in more explicit and responsive instruction than younger children—directing the learner's attention and referencing the learner's mistakes during instruction (e.g., Strauss & Ziv, 2012; Strauss et al., 2002; Wood et al., 1995). For example, Strauss and colleagues (2002) found that 3-year-olds simply demonstrated the correct move in a game following a learner's mistake, whereas 5-year-olds directly addressed this mistake in their explanations (e.g., "Look, the dice shows red, so I pick a red flower, not blue, see?"). Thus, we also hypothesized that older children would be better than younger children at adjusting *what* they taught each puppet based on that puppet's unique mistake.

In summary, we expected that older children would be better than younger children at making judgments about the puppets' knowledge based on their mistakes, at using more explicit teaching strategies, and at providing information that matched the puppets' mistakes.

Method

Participants

A total of 48 children participated. Children were divided into three age groups: 11 3-year-olds (5 girls, *M* = 3.48 years, *SD* = 0.33, range = 3.00–3.92), 18 4-year-olds (9 girls, *M* = 4.39 years, *SD* = 0.34, range = 4.00–4.92), and 19 5-year-olds (8 girls, *M* = 5.30 years, *SD* = 0.28, range = 5.00–5.92). Children were recruited from two local preschools in the Boston area of the northeastern United States. Although information about family socioeconomic status and ethnicity was not collected, these preschools serve families from middle to upper-middle class, and families were primarily of European American descent.

Materials

The game involved a small magnetic whiteboard and six painted 0.5 × 0.5-inch wooden squares: three pieces painted black (nonmagnetic) and 3 pieces painted red on one side and black on all other sides (one side containing a nonvisible magnet). The learners were four puppets matched to each child's gender. The puppets were 13 inches tall with a 12-inch arm span. Each puppet wore a different-colored shirt (i.e., yellow, green, blue, or red)

Procedure

Children participated in two phases: a *familiarization* phase and an *experimental* phase. During the familiarization phase, children learned how to play the game. During the experimental phase, children watched four puppets play the game. Immediately after each puppet played the game, children were asked to select a knowledge category to describe how much the puppet understood about the game based on their observation of the puppet and to teach the puppet so that it would be better at playing the game. Each phase is described in detail below.

Familiarization phase

To begin, the experimenter first ensured that children could identify the different-colored pieces and then said, "This is a very simple game. In this game, you have to put a piece inside the red square on this whiteboard. If you do that, then you win! If you don't put the piece inside the square, then you don't win. There are two types of pieces: red pieces and black pieces. The red pieces stick and the black pieces don't stick. See? You have to put a red piece inside the square to win. If you don't put a red piece inside the square, you lose." Children were invited to play with the remaining pieces and were asked four questions: (a) "Where do you have to put the pieces in the game?" (b) "What pieces do you need to use in the game?" (c) "Which pieces stick to the board?" (d) "Which pieces do not stick to the board?" All children correctly answered the questions, suggesting that the game was simple enough for even the youngest learners to understand.

Experimental phase

To introduce the puppets, the experimenter said, "Okay, now we are going to watch puppets play the game. Let's pretend they are real people. They played the game before, but they might make some mistakes, so pay close attention." Each puppet greeted children by looking at them and saying, "Hi, my name is . . . and I'm going to play the game." The first three puppets made errors; two puppets made a single, but different, mistake (correct piece, wrong location; wrong piece, correct location), and the third puppet made two mistakes (wrong piece, wrong location). The fourth puppet played the game correctly (expert). The puppet who played the game correctly was always presented last. The three puppets who made mistakes were presented in random order.

Immediately following each puppet's turn at playing the game, children were asked two questions: (a) "Do you think [puppet's name] played the game correctly?" (b) "Does [puppet's name] understand nothing, some things, or everything about the game?" These knowledge categories were accompanied by hand gestures to help children understand the categories (i.e., no gap between the experimenter's two hands for nothing, a medium gap for some things, and a large gap for everything).

Next, children were asked *to teach* the puppet so that the puppet "could play the game better." Note that children were not asked to teach the fourth puppet who had played the game correctly. A second experimenter recorded children's verbal and nonverbal actions. This allowed us to code for the manner by which children provided instruction (i.e., showing, telling, or providing a contrast) as well as the content of their instruction (i.e., focus on the piece, focus on the location, or both rules).

Results

We begin by investigating age-related developments in children's ability to select knowledge categories that matched the number of mistakes made by the puppets, age-related developments in the strategies children used when teaching the puppets, and age-related developments in the number of rules children taught to the two puppets that made only one mistake. We conclude by examining the relations among the teaching strategies children used, their selection of knowledge categories, and the number of rules they taught to each puppet.

Age and children's selection of knowledge categories

All 48 children (100%) stated that the puppet who made no mistakes played the game correctly and stated that the puppet who made two mistakes did not play the game correctly. All but 1 of the children (47 of 48, 98%) stated that both puppets who made one mistake did not play the game correctly. Thus, all children were able to identify whether the puppets did or did not play the game correctly.

Next, children were asked whether the puppet understood nothing, some things, or everything about the game. If children were keeping track of the number of rules, they should infer that the puppet who played correctly (100% accurate) understood *everything* about the game, the two puppets who each made one mistake (50% accurate) understood *some things* about the game, and the puppet who made two mistakes (0% accurate) understood *nothing* about the game.[1]

To evaluate children's ability to select knowledge categories reflecting the puppets' differing understanding, we created two sets of scores. First, we coded for whether children's selection of knowledge categories indicated that making no mistakes reflected a greater understanding than making mistakes (*correct > not*). To obtain a score of 1 on correct > not, children needed to judge that the knowledge of the puppet who made no mistakes was greater than the knowledge of the two puppets who each made one mistake (i.e., location mistake, color mistake) *and* greater than the knowledge of the puppet who made two mistakes (i.e., location mistake and color mistake). Second, we coded for whether children's selection of knowledge categories indicated a nuanced understanding of the relationship between the number of mistakes made and the learner's understanding of the game (*correct > partially correct > not*). To receive a score of 1 on correct > partially correct > not, children needed to receive a score of 1 on correct > not *and* select a greater knowledge category for the two puppets who made one mistake than for the puppet who made two mistakes.[2] Together, these two measures track children's ability to make increasingly nuanced and explicit distinctions between puppets who did and did not make mistakes (correct > not) and between puppets who differed in the number of mistakes they made (correct > partially correct > not).

[1] In Fig. S1 of the online supplementary material, we display for each puppet and age group the proportion of children who attributed each knowledge category.

[2] In Table S2 of the supplementary material, we display the proportion of children who passed each individual contrast (e.g., location mistake > both mistakes, color mistake > both mistakes). We also provide evidence showing that children viewed the location mistake as equivalent to the color mistake.

In Table 1, we display the proportions of children in each age group whose selection of a knowledge categories matched the logic that (a) correct > not and (b) correct > partially correct > not. Inspection of this table reveals that for all three age groups, children were better at indicating differences in understanding (correct > not) than between differences in misunderstanding (correct > partially correct > not): Wilcoxon signed-rank tests, 3-year-olds, $Z = 2.24$, $p < .05$, $r = .68$; 4-year-olds, $Z = 3.87$, $p < .001$, $r = .91$; 5-year-olds, $Z = 3.46$, $p < .001$, $r = .79$. In addition, there were age-related differences on both measures: correct > not, $\chi^2(2, N = 48) = 9.84$, $p < .01$, $V = .45$; correct > partially correct > not, $\chi^2(2, N = 48) = 5.68$, $p = .058$, $V = .34$. Specifically, children's scores on correct > not improved significantly between 3- and 4-year-olds, $\chi^2(1, N = 29) = 6.44$, $p < .05$, $V = .47$, but not between 4- and 5-year-olds, $\chi^2(1, N = 29) = 0.003$, $p = .95$. The 5-year-olds' scores on correct > partially correct > not were marginally higher than those of 3-year-olds, $\chi^2(1, N = 30) = 3.47$, $p = .06$, $V = .34$, and 4-year-olds, $\chi^2(1, N = 37) = 2.93$, $p = .09$, $V = .28$, and were significantly higher relative to 3- and 4-year-olds combined, $\chi^2(1, N = 48) = 5.48$, $p < .05$, $V = .34$. There were no differences between 3- and 4-year-olds' scores, $\chi^2(1, N = 29) = 0.63$, $p = .43$.

Age and children's use of different teaching strategies

To explore children's teaching behaviors, we coded children's teaching into three mutually exclusive categories. *Showing* was defined as physically demonstrating how to play the game by *silently* placing the red piece inside the red square. *Telling* was defined as verbally stating the rules of the game (e.g., "You need to put the red ones in the square"). *Contrasting* was defined as using contrasting language to state what should be done and what should not be done (e.g., "Don't put it on the outside; you did the red piece, which is correct, but you need to put it on the inside," "Don't take a black one; take a red one in the middle"). A research assistant blind to the hypotheses of the study and the first author (S.R.) coded all transcripts. During coding, both the research assistant and S.R. were blind to children's age, gender, and selection of knowledge categories. Agreement was 96% ($\kappa = .93$). Disagreements were resolved through discussion.

The distribution of teaching strategies children used did not differ significantly (Friedman's test) across the three puppets for 3-year-olds, $\chi^2(2, N = 33) = 0.95$, $p = .62$, 4-year-olds, $\chi^2(2, N = 44) = 0.19$, $p = .92$, and 5-year-olds, $\chi^2(1, N = 48) = 0.55$, $p = .76$.[3] As a result, we grouped children according to the teaching strategy they used most frequently (i.e., two of three times).[4]

In Fig. 1, we display the proportions of children who consistently used each strategy by age group. Inspection of this figure reveals a clear developmental trend. Children's consistent use of showing decreased with age, whereas children's consistent use of verbal strategies (telling and contrasting) increased with age, a significant difference, $\chi^2(2, N = 48) = 8.02$, $p < .05$, $V = .41$. Specifically, 5-year-olds consistently used verbal teaching strategies significantly more often than 3-year-olds, $\chi^2(1, N = 30) = 7.75$, $p < .01$, $V = .51$, and marginally more often than 4-year-olds, $\chi^2(1, N = 37) = 3.40$, $p = .07$, $V = .30$. There were no differences between 3- and 4-year-olds, $\chi^2(1, N = 29) = 1.45$, $p = .23$.

Age and children's provision of information based on puppets' unique mistake

To test whether children's ability to address the *unique* mistake of each puppet varied with age, we coded whether children explicitly provided only instruction about the color rule to the puppet who made the color mistake and provided only instruction about location to the puppet who made the location mistake. Alternatively, children might have been over-informative (i.e., demonstrating or telling both rules despite the fact that the puppet demonstrated a mistake with only one of them). For example, a child who stated "You have to put red squares in the middle" when teaching the puppet

[3] In Fig. S3 of the supplementary material, we display for each puppet and age group the proportion of children who used each teaching strategy.

[4] Only 1 child did not fit into these mutually exclusive categories. That child taught by showing once, telling once, and contrasting once. The child was coded as consistently telling because the child used a verbal teaching strategy two of the three times. Our statistical conclusions do not change whether that child should be included or removed from the analyses. Thus, this child was retained for all subsequent analyses.

Table 1
Proportions of children (by age) whose selection of a knowledge category for each puppet's understanding of the game reflected that (a) correct > not and (b) correct > partially correct > not.

	3-year-olds (n = 11)	4-year-olds (n = 18)	5-year-olds (n = 19)
Correct > not	.45	.89	.89
Correct > partially correct > not	0	.06	.26

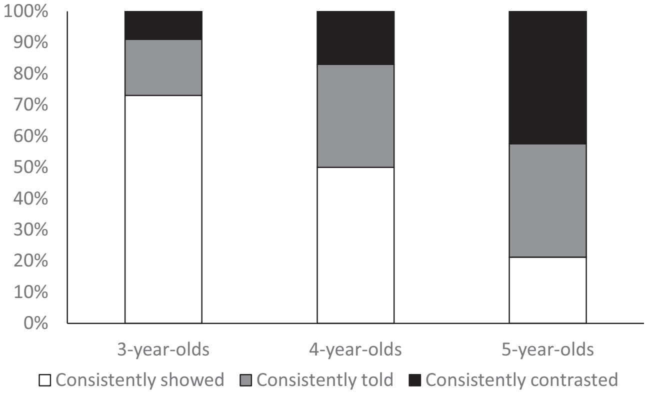

Fig. 1. Percentages of 3-, 4-, and 5-year-old children who consistently showed, consistently told, and consistently contrasted when teaching the three puppets who made mistakes.

who made the color mistake received a score of 0, whereas a child who said "You have to use the red one" received a score of 1. A research assistant blind to the hypotheses of the study and S.R. coded all of the teaching transcripts. During coding, both the research assistant and S.R. were blind to children's age, gender, and selection of knowledge categories. Agreement was 97% (κ = .92). Disagreements were resolved through discussion.

In Fig. 2, we display the percentages of 3-, 4-, and 5-year-olds who explicitly addressed the unique mistake for zero, one, or two of the puppets. Inspection of this figure reveals that older children explicitly addressed the specific mistake at least once (i.e., explicitly addressed the specific mistake one of two times *or* two of two times) significantly more often than younger children, $\chi^2(2, N = 48) = 7.00$, $p < .05$, $V = .38$. Specifically, 5-year-olds explicitly addressed the specific mistake of the puppet more often than 3-year-olds, $\chi^2(1, N = 30) = 4.47$, $p < .05$, $V = .39$, and more often than 4-year-olds, $\chi^2(1, N = 37) = 4.88$, $p < .05$, $V = .36$. There were no differences between 3- and 4-year-olds, $\chi^2(1, N = 29) = 0.07$, $p = .79$.

Relations among children's use of teaching strategies, selection of knowledge categories, and provision of information based on puppets' unique mistake

Our previous analyses indicate that 5-year-olds were better than 3- and 4-year-olds at selecting knowledge categories based on the number of mistakes that puppets made, that they used verbal teaching strategies more often than younger children, and that they were more likely to target their instruction to the puppets' unique mistake.

One explanation for older children's higher performance on the knowledge category task and on the teaching task (i.e., more targeted teaching) is their more developed language (and theory of mind) abilities relative to younger children. On this hypothesis, children's complex language (i.e., contrasting) might be related to their ability to complete the knowledge category task and their ability to teach to the unique mistake of the learner.

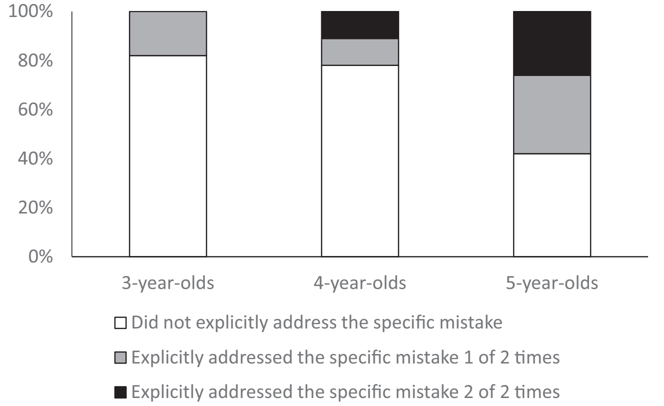

Fig. 2. Percentages of 3-, 4-, and 5-year-old children who explicitly addressed the mistake of zero, one, and two puppets.

In Table 2, we display the proportions of children whose instruction addressed the puppets' unique mistake as a function of children's teaching style (showing, telling, or contrasting). Inspection of this table reveals that children who consistently contrasted directly addressed the puppets' unique mistake more often than children who consistently told and that, in turn, children who consistently told explicitly addressed the puppets' unique mistake more often than children who consistently showed, $\chi^2(4, N = 48) = 23.32$, $p < .001$, $V = .54$.

Of particular importance is the comparison between children who consistently told and children who consistently contrasted. These two groups did not differ in age, $F(1, 25) = 0.46$, $p = .50$. However, children who consistently contrasted were more proficient at selecting knowledge categories based on the puppets' mistakes, correct > not, $\chi^2(1, N = 27) = 3.76$, $p = .05$, $V = .37$; correct > partially correct > not, $\chi^2(1, N = 27) = 5.87$, $p < .05$, $V = .46$, and at directly addressing the puppets' mistakes during instruction, $\chi^2(1, N = 27) = 10.85$, $p < .01$, $V = .63$, than children who consistently told.

Discussion

We explored the development of children's ability to infer knowledge from mistakes, the development of children's teaching strategies, and the development of children's ability to tailor the information they teach to match their pupils' unique mistakes. We observed concurrent development in these three abilities. The 5-year-olds were better than the 3- and 4-year-olds at inferring knowledge from mistakes. They used more explicit and verbal teaching strategies than 3- and 4-year-olds such as contrasting the learner's prior behavior with what should be done (Davis-Unger & Carlson, 2008; Recchia et al., 2008; Strauss & Ziv, 2012; Strauss et al., 2002; Wood et al., 1995) and more often provided information that directly addressed the learner's mistakes rather than being over-informative.

Before further delving into the implications of these findings, it is important to first consider whether developmental change in children's teaching abilities, particularly their use of contrastive teaching strategies, may be related to children's memory or to their ability to emulate the experimenter's teaching behaviors. During the familiarization phase, the experimenter explicitly provided contrastive information about the rules of the game. Thus, if children had simply been imitating the experimenter's instructions when instructing the puppets themselves, we would expect that children would have repeated both contrasts (location and color) rather than verbalizing only the contrast that matched the mistake made by each puppet. The fact that we did not observe this pattern (i.e., children who used contrastive language tended to not be over-informative but rather targeted their contrast to the unique mistake made by the puppet) makes it unlikely that their use of contrastive language reflects improved memory or imitative abilities.

Table 2
Ages and proportions of children who selected knowledge categories reflecting that (a) correct > not and (b) correct > partially correct > not and proportions of children whose instruction directly addressed the puppets' mistake as a function of children's teaching style.

	Teaching strategy		
	Consistently showed (n = 21)	Consistently told (n = 15)	Consistently contrasted (n = 12)
Age (*SD*) (years)	4.08 (0.79)	4.84 (0.59)	4.99 (0.51)
Selection of knowledge categories			
Correct > not	0.71	0.73	1.00
Correct > partially correct > not	0.10	0.00	0.33
Mistake instruction match			
Did not explicitly address the puppets' specific mistake	0.95	0.67	0.08
Explicitly addressed the specific mistake one of two times	0.05	0.27	0.42
Explicitly addressed the specific mistake both times	0.00	0.08	0.50

Below, we discuss the parallels between the development of children's ability to infer knowledge from mistakes and previous research on children's ability to track the mistakes of potential teachers. We then discuss the implications and limitations of our finding of parallel age developments and, thus, associations between children's ability to infer knowledge from mistakes and their engagement in more responsive teaching. We conclude by discussing the implications of these findings for future research on children's development as teachers.

Our comparison of the knowledge categories that children selected for each puppet revealed that children found it easier to track large differences in knowledge (i.e., correct > not) than to track smaller differences (i.e., correct > partially correct > not). This finding replicates, using a different methodology, previous findings showing that children are first capable of making judgments about the overall accuracy of their teachers before being able to make judgments about their relative accuracy (e.g., Corriveau et al., 2009; Pasquini et al., 2007). However, slight age-related changes are notable when comparing across the selective learning literature and our work on children's selective teaching. Specifically, whereas children are able to track differences in a teacher's relative accuracy by 4 years of age (Corriveau et al., 2009; Pasquini et al., 2007), our findings highlight a sharp difference between 3- and 4-year-olds' and 5-year-olds' ability to infer knowledge from mistakes. However, this difference must be interpreted cautiously given that we asked children to provide independent ratings of each puppet's knowledge rather than asking them to make a binary choice between pairs (i.e., which one knows more?). Providing independent ratings is more difficult for children than answering a binary question (Gweon & Asaba, 2015). Thus, we might have underestimated younger children's abilities to detect differences in the knowledge of the puppets—especially when comparing between a puppet who made one mistake and the puppet who made two mistakes.

The fact that children's ability to infer knowledge from mistakes undergoes similar age-related improvements across the preschool years for both children's selective learning and teaching suggests a similar underlying cognitive ability. We anticipate that children's developing theory of mind may be such a capacity. False belief understanding may be a particularly strong predictor of children's ability to infer knowledge from mistakes because mistakes are symptomatic of a false belief. False belief tasks present children with a conflict between a character's beliefs about reality (e.g., Band-Aid boxes have Band-Aids inside) and reality (e.g., there are candles inside). Similarly, attributing knowledge based on mistakes or selecting between teachers who differ in their accuracy requires children to weigh a learner's or teacher's actual understanding (i.e., his or her beliefs) against what complete understanding would look like (i.e., reality). Indeed, previous research has found a significant relationship between children's teaching and their understanding of false beliefs (Davis-Unger & Carlson, 2008; Strauss et al., 2002) as well as children's understanding of learning and their understanding of false beliefs (Sobel, 2015; see also Sobel, Li, & Corriveau, 2007).

Differences in the importance of theory of mind to solve selective learning and teaching tasks might also shed light on the age-related differences we found between selective learning and teaching tasks. Specifically, although the research above highlights the relationship between selective teaching and false belief understanding, this relationship between children's selective trust of a more accurate informant and their understanding of false beliefs is more mixed. Some research has found a strong relationship between selective learning and false belief (DiYanni & Kelemen, 2008; Lucas, Lewis, Pala, Wong, & Berridge, 2013), but other research has not (Pasquini et al., 2007; see also Brosseau-Liard, Penney, & Poulin-Dubois, 2015). Thus, although theory of mind might be an important precursor to engage in selective teaching following the recognition of a mistake, it might not be a prerequisite for selective learning.

Moreover, the relation between false belief and selective learning and teaching should be interpreted with caution. There is a strong link between children's false belief understanding and children's general language abilities (Milligan, Astington, & Dack, 2007), and the majority of previous studies mentioned above did not control for language. Therefore, it is possible that children's ability to use their pupils' and teachers' mistakes when learning and teaching reflects children's increasing engagement in conversations and, particularly, in the perspective taking required for conversations to conform to Grice's (1975) maxims (Bernard & Deleau, 2007) rather than just their theory of mind capacities.

Our results demonstrate parallel developments in children's ability to scaffold their teaching and their ability to infer knowledge from learners' mistakes. This parallel development further strengthens the theoretical distinction between helping and teaching. Whereas helping relies on understanding goal-directed behavior to help another person complete an immediate goal (Warneken & Tomasello, 2006), children's teaching aims to provide the learner with the tools to solve novel problems in the future and relies on the ability to track what the learner understands. The ability to track what the learner does and does not understand, as well as the ability to identify and selectively teach information that is hard to discover (Ronfard, Was, & Harris, 2016), makes young children into precocious teachers who are able to support the development of cumulative culture at an early age (Boyd & Richerson, 1985; Dean, Kendal, Schapiro, Thierry, & Laland, 2012; Tomasello, 1999).

Limitations of our current study (and of research on children's teaching in general) are our reliance on a relatively Western-educated industrialized rich democratic sample (Henrich, Heine, & Norenzayan, 2010) and the fact that we did not obtain a measure of both children's *and* their guardians' beliefs about teaching. This is because how children teach and, by implication, their beliefs about teaching and learning vary based on their culture's beliefs and practices around teaching (Maynard, 2004). Consequently, how children teach in response to a learner's mistakes is likely to depend on their cultural context. Consider children's question-asking behaviors and vocabulary development. Parents vary in the number of questions they ask their children (Hart & Risley, 1992), and parents who ask more questions to their children in turn have children who ask more questions (Tizard & Hughes, 1984). This variation in parents' question-asking behavior and its influence on children's own question asking may be due to differences in parents' beliefs about how children learn best and about how children should be taught—parents' folk psychologies and pedagogies (Astington & Pelletier, 1996; Olson & Bruner, 1996; Strauss et al., 2002). Variation in parents' teaching styles (and the concomitant variation in children's teaching styles) may be similarly related to parents' beliefs. Indeed, recent research suggests that social class differences in parents' child-directed speech are mediated by parents' beliefs about child development (Rowe, 2008). Thus, it is critical that future research continue to explore the development of children's teaching in different cultures. We suspect that across cultures children will increasingly provide better scaffolding to their pupils as they develop the ability to track their pupils' mistakes but that the strategies by which children scaffold may differ across cultures; in a culture that does not emphasize verbal instruction children's *nonverbal* teaching will become more targeted and responsive to learners' mistakes, whereas in a culture that emphasizes verbal instruction children's *verbal* teaching will become more targeted and responsive to learners' mistakes (Rogoff, 2003).

Previous empirical and theoretical work on teaching has emphasized either the developing cognitive abilities of child teachers (e.g., Strauss et al., 2002) or the receptivity of children to teaching (Csibra & Gergely, 2009). As highlighted by Strauss, Calero, and Sigman (2014), now is the time for research to consider the development of interactions between teachers and learners. We believe that a cross-cultural and longitudinal study of children's engagement in teaching and learning tasks with their parents would be especially revealing because it would help to shed light on how culture and parenting beliefs shape how parents teach and, in turn, how their children teach.

In summary, we have provided the first evidence that children's ability to infer a learner's knowledge state directly from the learner's behavior parallels developments in children's ability to better scaffold their instruction by correcting learners' actions and beliefs in real time—a skill critical to the transmission of complex knowledge and skills (Morgan et al., 2015; Zwirner & Thornton, 2015) and, as a result, to our remarkable success as a species.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jecp.2016.05.006.

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