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Children teach methods they could not discover for themselves

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ABSTRACT

Across three studies (*N* = 100), we explored whether and, if so, under what circumstances children's self-discovered knowledge impacts their transmission of taught information. All participants were taught one of several methods for extracting rewards from a box. Half of the participants were also given an opportunity to discover their own method prior to receiving such instruction. Across studies, we varied the transparency of the taught method relative to the method children could discover on their own. When asked to teach a naive pupil about the box, children who did not explore the box always transmitted what they were taught. Children in the Exploration + Instruction condition were also likely to transmit what they had been taught, but they were especially likely to do so when the taught method was more opaque than the method they had discovered for themselves. Thus, children faithfully transmit what they have been taught, but only when that information is difficult to discover.

Introduction

The human capacity for cumulative culture is unparalleled (Boyd & Richerson, 1985; Tomasello, 2009) and attributable to a suite of species-unique sociocognitive abilities (Dean, Kendal, Schapiro, Thierry, & Laland, 2012). Teaching allows for the efficient and faithful transmission of information

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and is likely to have evolved for this purpose (Csibra & Gergely, 2009, 2011; Fogarty, Strimling, & Laland, 2011). Because teaching requires an investment of time and resources on the part of the teacher, teaching is theorized to be adaptive only in cases where the learner could not gain the information on his or her own (Fogarty et al., 2011; Thornton & Raihani, 2008). Thus, teachers are likely to differentiate between information that *must* be taught (because the learner is *unlikely* to be able to learn it on his or her own) and information that *can* be taught but does not need to be taught (because the learner is *likely* to learn it on his or her own). However, neither current theoretical models of teaching (Csibra & Gergely, 2009, 2011; Fogarty et al., 2011; Thornton & Raihani, 2008) nor prior empirical works on the development of teaching in children (e.g., Strauss & Ziv, 2012; Strauss, Ziv, & Stein, 2002; Wood, Wood, Ainsworth, & O'Malley, 1995) provide an explanation for how teachers identify information as worthy of transmission.

What teachers decide to teach a novice is likely to depend on the teachers' own learning history. More specifically, their learning history can give them a sense of what is an easily discoverable method (information that could, in principle, be taught but does not need to be taught) and what is a more opaque method (information that should be taught). When asked to teach a novice, teachers can decide to teach what they were taught, what they discovered, or a combination of what they were taught and what they discovered. If individuals have been taught a method of solving a particular problem, they will typically teach that method to a naive other because they are likely to assume that the information they have been taught is accurate and exhaustive (Bonawitz et al., 2011). However, if they have had an opportunity to discover a method for themselves before being taught, they will be more selective in transmitting the information that they were taught. Thus, if the method they are taught is just as transparent as the one they have discovered for themselves, they will be as likely to teach their own method as the taught method (or to teach both). However, if they are taught a more opaque method than the one they have discovered for themselves, they will be more likely to teach that method rather than their own method. Given that they did not discover the more opaque method themselves, they can infer that a novice would be unlikely to discover it. Such a pattern would suggest that a teacher's own learning history helps the teacher to identify what information should be taught in a way that favors the transmission of hard-to-discover information.

There is, however, a plausible alternative to this learning history heuristic, namely that teachers will teach what they were initially taught—no matter what their learning history. This strategy would faithfully preserve taught information through successive generations and require no reflection on the part of teachers about their own learning history. We know that both adults and children imitate unnecessary causally irrelevant actions (e.g., McGuigan, 2012; McGuigan, Makinson, & Whiten, 2011) and will do so even when such overimitation is costly (Flynn & Smith, 2012; Lyons, Damrosch, Lin, Macris, & Keil, 2011). Moreover, children overimitate even after they have discovered a more efficient solution themselves (Nielsen & Tomaselli, 2010) and after they have explicitly marked causally irrelevant actions as "silly" (Lyons et al., 2011). This suggests that overimitation does not result from a lack of knowledge about which actions are necessary and which actions are not; rather, it appears that overimitators view taught methods as normative (Kenward, Karlsson, & Persson, 2011). In support of this interpretation, adults are less likely to overimitate when a method is demonstrated by only a minority of experimental models (McGuigan, Gladstone, & Cook, 2012). Furthermore, children criticize others who have been shown irrelevant actions by a model (along with the child) but later omit them (Kenward, 2012; Keupp, Behne, & Rakoczy, 2013). Given the fidelity with which children reproduce what they are shown as pupils, as well as the criticism they direct at less faithful pupils, it is feasible that they adopt a similar stance in the role of teacher, namely to faithfully model whatever actions they were shown.

To determine whether children's learning history impacts their transmission of information, we conducted three studies ($N = 100$). We focused our investigation on preschool-aged children because they have less formal teaching experience than adults but do engage in teaching others (e.g., Gelman, Ware, Manczak, & Graham, 2013; Gweon, Chu, & Schulz, 2014; Strauss & Ziv, 2012; Strauss et al., 2002). In all three studies, children were randomly assigned to an Instruction Only condition or to an Exploration + Instruction condition. In each condition, they were presented with a novel puzzle box that contained rewards and were taught a method for extracting these rewards. Children in the Exploration + Instruction condition were also given an opportunity to discover their own method prior to receiving such instruction. Children in both conditions were then asked to teach a naive puppet how to use the box. We varied the opacity (efficiency and ease of discovery) of the taught information relative to the information that children could discover for themselves. In the first study, the taught method was harder to discover and less efficient than the self-discovered methods. In the second study, the taught method was no harder to discover and just as efficient as the self-discovered method. Finally, in the third study, the taught method was harder to discover but as efficient as the self-discovered method.

In addition, in Study 1, we ran two Exploration + Instruction conditions: one in which the experimenter *supervised* children's exploration of the box and one in which children's exploration of the box was *unsupervised*. We included these two conditions to test whether the presence of the experimenter during children's initial exploration influenced their transmission of taught information. We reasoned that the presence of the teacher during children's exploration might lead children to construe the teacher's subsequent instruction as a corrective to what they had discovered and, therefore, reduce their transmission of that self-discovered method.

In the absence of an opportunity to explore the box (i.e., in the Instruction Only condition), we anticipated that children would teach the method they were taught across all three studies. In the Exploration + Instruction condition, we expected that children's faithful transmission of taught information would vary with the opacity of the taught information. In Studies 1 and 3, children should be likely to teach what they were taught because the taught method was more opaque than the methods children could discover on their own. In contrast, children in Study 2 should display a much weaker tendency to teach what they were taught because the taught method was no more opaque than the method children could discover on their own.

On the other hand, if children's learning history does not impact how they view the information they are taught, they should faithfully teach what they were taught across all three studies—not just in the Instruction Only condition but also in the Exploration + Instruction condition.

Study 1

Method

Participants

A total of 36 preschool-aged children (21 girls; M_{age} = 5.49 years, SD = 0.84, range = 4.10–6.73) participated in this study. Children were randomly assigned either to an Instruction Only condition (n = 12; 6 girls; M_{age} = 5.48 years, SD = 0.82, range = 4.12–6.62) or to one of two types of Exploration + Instruction condition: Supervised Exploration + Instruction (n = 12; 7 girls; M_{age} = 5.36 years, SD = 0.79, range = 4.13–6.73) or Unsupervised Exploration + Instruction (n = 12; 8 girls; M_{age} = 5.62 years, SD = 0.96, range = 4.10–6.67). Participants were recruited from, and tested in, an urban museum in the northeastern part of the United States. We were not permitted to gather demographic information, but the museum's surveys show that approximately 70% of the visitors are White and of high socioeconomic status (SES).

An additional 18 children were recruited but excluded from the analyses: 4 who elected to stop the study, 5 who did not learn the experimenter's method of opening the puzzle box after three attempts, 5 who failed to successfully retrieve stickers on their own during the exploration phase, 1 who discovered the experimenter's method during exploration, 1 who was dropped due to parental intervention, and 2 who were dropped because of experimenter error. This high number of excluded children may be partially attributable to the experimental setting; the study took place in the corner of a large room in the museum that contained other activities that may have proven distracting for participants.

Novel box

Children were presented with a cardboard puzzle box (31.5 × 24.5 × 8.5 cm) containing two stickers. The top of the box was transparent. The box was accompanied by three wooden dowels (31 cm long × 9 cm wide) with differently shaped clay stoppers (triangle, circle, and square) on one end. This puzzle box was designed to (a) be easily solvable by a child, (b) have several possible equally valid solutions, and (c) be operable by a single person. To this end, we pilot-tested the toy with 13 children

(M_{age} = 4.91 years, range = 3.88–6.87). Children were invited to explore the toy and to extract the stickers; of these 13 children, 1 (8% of participants) was unable to extract the stickers, 3 (23%) used one stick, and 9 (69%) opened the lid. We then taught participants how to open the toy using the experimenter's method and asked them to reproduce the solution. Participants needed an average of 1.5 demonstrations (range = 1–3) to successfully reproduce the experimenter's method.

Procedure

Children were seated at a small table across from a female experimenter (E1). In all three conditions, the experimenter first introduced the box and pointed out the stickers embedded inside. In both of the Exploration + Instruction conditions, E1 invited children to attempt to extract the stickers using any method they wanted. In the Supervised Exploration + Instruction condition, E1 watched as children interacted with the box but did not comment on their performance. In the Unsupervised Exploration + Instruction condition, E1 told children that she needed to finish writing something and then turned her back to the children during the exploration phase. Children were instructed to inform E1 once they had successfully retrieved both stickers. Children in the Instruction Only condition did not participate in this exploration phase. Children who explored the box came up with different methods for retrieving the stickers—for example, opening the lid of the box and retrieving the stickers with their hands or opening the lid of the box and using the dowels to pick up the stickers.

Next, in both of the Exploration + Instruction conditions and in the Instruction Only condition, E1 told the children, "Now, I am going to *teach* you how the toy works. This is how you get the stickers out." She then demonstrated an inefficient and nonintuitive method of extracting the stickers that required four steps. Her demonstration was accompanied by speech narrating her actions. Each step required using one of three tools (wooden dowels that were identical except for the shape pictured on one end) to push a wooden block holding a sticker through the box. The shapes on the dowels matched to different sides of the box. Pushing the square stick through a hole in the square side, the experimenter demonstrated how to move the sticker to the middle of the box and then used the circle stick to completely dislodge the sticker from the box. This was repeated for the other sticker (using the triangle stick on the triangle side and then the circle stick on the circle side). Children were then asked to reproduce E1's method. If they failed to reproduce the experimenter's method, the toy was reset and the demonstration was repeated up to two additional times. There were no significant differences in the average numbers of demonstrations that children needed in the Unsupervised Exploration + Instruction condition (M = 1.42, SD = 0.51), the Supervised Exploration + Instruction condition (M = 1.42, SD = 0.67), and the Instruction Only condition (M = 1.50, SD = 0.52), $F(2,33)$ = 0.08, p = .92. Note that all children in the two Exploration + Instruction conditions had discovered a more efficient means of obtaining stickers from the box than the one subsequently taught by the experimenter.

Once children had successfully reproduced E1's method, the experimenter reset the box and said: "Oh, I forgot that I need to call someone. I need to go do that, so [Experimenter 2, E2] will finish the game with you." Although E2 had not been involved with the study up until this point, she was not completely unfamiliar to the children because they had been introduced to her at the beginning of the study. E1 then walked away and stayed out of the children's view until the end of the study.

On switching places with E1, E2 brought out an alien puppet who she introduced as "Zorg." Borrowing from Gelman et al. (2013), Zorg was described as "from a planet that is far away and very different from here." Children were then told, "Zorg doesn't know anything about our world, and Zorg wants you to teach her/him [Zorg's gender was matched to the gender of the participant] about the toy. Can you teach Zorg how the toy works? And you know what, Zorg isn't going to talk right now, but she/he just wants to watch and listen."

Children received no further instructions and were then free to teach Zorg in any way they saw fit. After they had either stopped interacting with the box or Zorg or had extracted both stickers, E2 thanked them for teaching Zorg and then put Zorg out of sight.

Results

We coded children as teaching their own method, the experimenter's method, or both methods. As expected, all children in the Instruction Only condition taught only the experimenter's method.

However, children in the Supervised Exploration + Instruction and Unsupervised Exploration + Instruction conditions also taught only the experimenter's method. Thus, there was no difference in the type of information children taught Zorg in the three conditions (Fisher's exact test, $p = 1.00$). Results are shown in Fig. 1 (the Supervised Exploration + Instruction and Unsupervised Exploration + Instruction conditions are combined). Although children in the two Exploration + Instruction conditions had all found an alternate method that was more efficient and easier to discover than the one they had been taught, none of them taught that method to Zorg.

Study 2

For Study 2, we designed a new puzzle box that could be opened using identical actions (opening a red door or a blue door). There was no difference in the efficiency or ease of discovery of these two methods. If children use their own learning history to evaluate the information they are taught, they should be less prone to teach the experimenter's method when it is just as easy to discover as their own method. On the other hand, if children faithfully teach the method they have been taught because they regard that method as normative, they should teach the experimenter's method rather than their own method even when the experimenter's method is just as easy to discover as their own method.

Method

Participants

A total of 32 preschool-aged children (22 girls; $M_{age} = 5.59$ years, $SD = 0.61$, range = 4.20–6.53) were recruited to participate in the study at an urban museum in the northeastern part of the United States. Participants were randomly assigned to one of two conditions: Instruction Only ($n = 16$; 11 girls; $M_{age} = 5.57$ years, $SD = 0.67$, range = 4.20–6.53) and Exploration + Instruction ($n = 16$; 11 girls; $M_{age} = 5.61$ years, $SD = 0.58$, range = 4.63–6.48). An additional 5 children (2 in the Instruction Only condition and 3 in the Exploration + Instruction condition) were dropped from the study: 3 because they could not open the box by themselves, 1 because of experimenter error, and 1 because of parental interference (her mother told her how to open the box).

Novel box

A new puzzle box was constructed for Study 2. This wood and Plexiglass box (26.9 × 9.0 × 12.7 cm) contained a small cardboard star. Like the puzzle box used in Study 1, it was designed to be easily solvable by a child, to have more than one solution, and to be operable by a single person. However, unlike in Study 1, the experimenter's method and the child's method were designed to be mirror images of each other. They were equally efficient, intuitive, and easily discoverable. That is, to extract the star, children could either slide a red door or a blue door laterally. Importantly, only one door could be opened at a time. Thus, if children opened the red door during their exploration of the box, they could not open the blue door and vice versa. Children were then taught to obtain the star using the door they did not discover. To check whether children were able to discover a method on their own, we pretested the box with a separate group of 13 children (10 girls; $M_{age} = 4.83$ years, $SD = 1.10$, range = 3.42–6.97). Children were first invited to explore the toy and extract the star. All children were able to do this. Participants were then taught the alternate method by the experimenter (e.g., if they had opened the red door during exploration, the experimenter taught them to open the blue door), and the experimenter asked them to reproduce the solution. All of the pretest participants required only one demonstration to reproduce the experimenter's method without error. Thus, the pretest confirmed that children easily discovered one of the two methods of extracting the star and could also easily observe and learn the alternate method.

Procedure

The procedure for Study 2 was similar to that used in Study 1, with the following three modifications. First, because children had behaved similarly in the two Exploration + Instruction conditions of Study 1, only two conditions were included in Study 2: Instruction Only and Exploration + Instruction

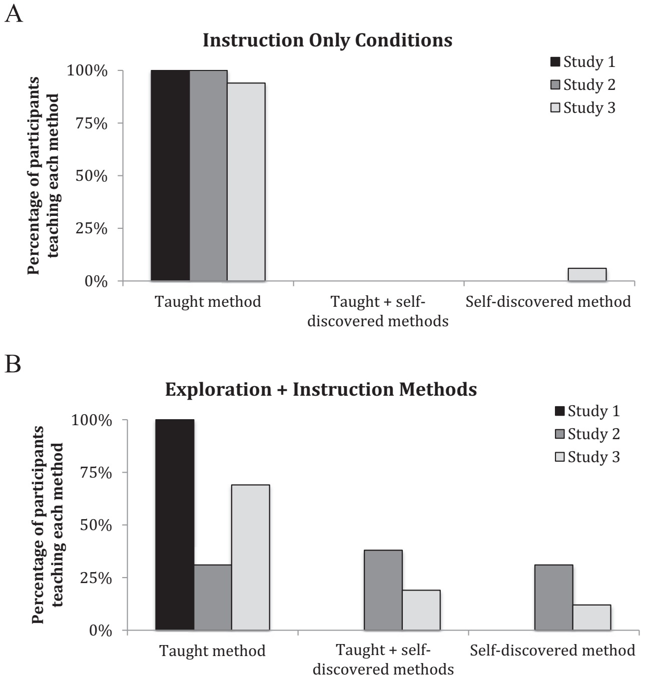

Fig. 1. Results from Studies 1 to 3 showing the percentages of participants who taught only the method they were taught, both the method they were taught and the method they discovered, and only the method they discovered for themselves in the Instruction Only condition (A) and the Exploration + Instruction condition (B).

(which was supervised by the experimenter). Second, following the instruction phase, children were not asked to reproduce the experimenter's method. Third, the alien puppet was replaced by a child puppet called "Jamie" (gender-matched to the participant), who was described as "just a little kid" and younger than the participants. We made this change in order to create a more realistic pedagogical context.

Results

As in Study 1, we coded children as teaching their own method, the experimenter's method, or both methods. Children were coded as teaching their own method when they taught the puppet how to open the box using the door not demonstrated by the experimenter. We coded responses as "both" if children either demonstrated both methods or demonstrated one method and talked about the other method. For example, children who showed the red method but said "you could also do blue" were coded as "both," as were children who said something like "you have to open a side and get it out" and then demonstrated only one side (we interpreted this kind of instruction as generic because it was not tied to a particular side of the box). Results are depicted in Fig. 1. In the Instruction Only condition, all children (100%) taught only the experimenter's method. By contrast, in the Exploration + Instruction condition, 31% taught the experimenter's method, 31% taught their own method, and the remaining 38% taught both methods. A Fisher's exact test confirmed that the distribution of children across these three teaching categories differed significantly by condition ($p < .001$).

Study 3

In Study 1, the taught method was more opaque than the method children discovered for themselves. When faced with the choice of what to teach, all children in the two Exploration + Instruction conditions ignored the method they had discovered for themselves and taught the experimenter's opaque method instead. In Study 2, the taught method was just as obvious as the method children discovered for themselves. When faced with the choice of what to teach in Study 2, children in the Exploration + Instruction condition were just as likely to teach either method—or to teach both methods. Thus, children did not privilege the method they had been taught when it was just as obvious as their own self-discovered method.

Based on the learning history hypothesis, we conclude that children in Study 1 favored the experimenter's method in their own teaching because they realized that it was more opaque than their own method, whereas children in Study 2 did not systematically favor the experimenter's method because it was as easy to discover as their own method. However, it could be argued that children taught the experimenter's method in Study 1 because it was more elaborate than their own method, not just because it was more opaque. That is, children in Study 1 may have interpreted the goal of the experimenter to be the teaching of a convention rather than of a skill, and this may have increased the fidelity of children's teaching because the cueing of a conventional teaching goal rather than an instrumental teaching goal increases imitative fidelity (Legare, Wen, Herrmann, & Whitehouse, 2015). We tested this hypothesis in Study 3 by ensuring that the experimenter's method was just as simple as the method children discovered for themselves even if it was more opaque.

Method

Participants

A total of 32 preschool-aged children (16 girls; M_{age} = 5.26 years, SD = 0.93, range = 4.00–6.90) were recruited to participate in the study at Boston area museums. Participants were randomly assigned to one of two conditions: Instruction Only (n = 16; 7 girls; M_{age} = 5.18 years, SD = 0.94, range = 4.02–6.90) and Exploration + Instruction (n = 16; 10 girls; M_{age} = 5.35 years, SD = 0.95, range = 4.00–6.71). An additional 5 children (3 in the Instruction Only condition and 2 in the Exploration + Instruction condition) were dropped from the study: 3 because they could not open the box when asked to teach, 1 because the child elected not to finish the study, and 1 because of experimental error.

Novel box

We created a new puzzle box for Study 3. This wooden box (22 × 18 × 13 cm) contained a small cardboard star. There were two methods for opening the box and extracting the star: (a) an intuitive and easily discovered method that required pulling a large and conspicuous handle on one side of the box (*handle method*) and (b) a less intuitive and less easily discovered method that required pushing on the edge of a flat side of the box, causing the side to pop open (*flat side method*). Although the methods differed in how easy they were to discover, they were equally simple to execute, with one requiring a pulling action and the other requiring a pushing action. We pretested this box with a separate group of 6 children (1 girl; M_{age} = 5.43 years, SD = 1.22, range = 3.91–6.87); all of these children spontaneously solved the box by pulling the handle. None of the children discovered the flat side method, but they were able to reproduce it after a single demonstration by the experimenter. This same pattern was observed in Study 3. All children in the Exploration + Instruction condition spontaneously discovered the handle method, and none discovered the flat side method.

Procedure

The procedure for Study 3 was identical to that used in Study 2 except that all children were taught how to push the flat side of the box.

Results

As in Studies 1 and 2, we coded children as teaching their own method, the experimenter's method, or both methods, and results are shown in Fig. 1. Children were coded as teaching their own method when they taught the puppet how to open the box using the handle method rather than the flat side method. In the Instruction Only condition, 94% of children taught the experimenter's method, 6% taught their own method, and none taught both methods. In the Exploration + Instruction condition, 69% taught the experimenter's method, 12% taught their own method, and 19% taught both methods.

A Fisher's exact test indicated that the distribution of teaching categories did not differ significantly by condition ($p = .21$). Thus, even when children had discovered a simple method to open the box, as teachers the majority passed on the opaque method they had been taught just as they did in the Instruction Only condition.

To further test whether children's faithful transmission of taught information varies with the opacity of that information, we compared, across the three studies, the proportion of children who showed a clear preference for taught information rather than self-discovered information by transmitting only the information they were taught (i.e., by not teaching the method they discovered on their own). In Study 1, the opacity of the taught information was the greatest; it was both harder to discover and more elaborate (less efficient) than children's self-discovered methods and, therefore, may have led children to infer that the goal of the experimenter was to teach a convention rather than a skill. In Study 3, the opacity of the taught information was intermediate; it was harder to discover but no more elaborate than children's self-discovered methods and, therefore, reduced the possibility that children inferred that the goal of the experimenter was to teach a convention rather than a skill. The taught information in Study 2 was the least opaque; it was as discoverable and as simple as the methods children could discover. Thus, if the opacity of taught information relative to children's knowledge impacts children's transmission of that information, we should observe that the proportion of children who faithfully transmitted only what they were taught in the Exploration + Instruction conditions is consistent with this ordering: Study 1 > Study 3 > Study 2. Indeed, this is what we found: Study 1 = 100%, Study 3 = 69%, Study 2 = 31%—a statistically significant difference (Fisher's exact test, $p < .001$). To follow up on these differences, we used a one-sided Fisher's exact test to compare the studies against each other. We used a one-sided test because we were testing a one-sided hypothesis—whether the study with the more opaque taught information had a higher proportion of children teaching only what they were taught. A greater proportion of children taught what they were taught in Study 1 than in Study 2 (100% vs. 31%, $p < .001$), and in Study 1 than in Study 3 (100% vs. 69%, $p < .01$). Finally, a greater proportion of children taught what they were taught in Study 3 than in Study 2 (69% vs. 31%, $p < .05$). Thus, the opacity of the taught method relative to the method children discovered on their own influenced the information children favored when teaching a naive other; the more opaque the method children were taught relative to the method they discovered, the more often they taught only that method to the naive other.

General discussion

Across three studies, we asked whether there are conditions under which children will refrain from teaching a method they have been taught and instead—or in addition—teach a method they have discovered for themselves.

In Study 1, children always taught the elaborate and opaque method they had previously been taught. They did this even if they had discovered a simpler and more obvious method on their own. By contrast, in Study 2, children were much less likely to teach a method they had been taught that was just as simple and obvious as the method they discovered for themselves. Finally, in Study 3, most children taught a method that had been demonstrated to them that was just as easy to execute as the method they discovered for themselves but less easy to discover. Indeed, the more opaque the taught method relative to children's self-discovered knowledge, the more children faithfully transmitted the information they were taught instead of the information they discovered for themselves.

These findings raise several interesting issues. First, they suggest that a teacher's own learning history influences what information the teacher passes on to others. Second, they underscore the importance of informational opacity and its potential relations to ritual or norm. Third, they raise questions about the processes by which children decide *how* and *what* to teach others.

Taken together, these results show that the *manner* in which children acquire information, as well as the *information* they acquire, influences what they choose to teach a naive learner. Children faithfully transmit taught information if it is the only information they possess. When they have two sources of information—their own self-discovered information and information they were taught—they prefer to teach information that is less obvious. More specifically, if they are shown a method comparable to a method they can easily discover for themselves, they do not favor the taught method when teaching a naive companion. But if they are shown a method they would not easily discover for themselves, they are likely to pass it on to a naive companion. This suggests that teaching favors the onward transmission of information that the *teacher* would have found difficult to acquire. This is consistent with theoretical models suggesting that teaching evolved to support the acquisition of difficult-to-acquire information (Csibra & Gergely, 2009; Fogarty et al., 2011; Thornton & Raihani, 2008). However, such models do not provide an explanation for how teachers identify what counts as difficult-to-acquire information. Our results suggest that one method available to teachers is their own learning history. If this is correct, the ability of human teachers to use their own learning history to decide what information to teach might prove to be one reason why humans are so adept at transmitting knowledge over time. The ability to use one's learning history catalyzes the impact of teaching on cumulative culture by ensuring that teachers funnel their energy into teaching the most difficult-to-acquire skills (i.e., the skills that the learner is unlikely to be able to acquire on his or her own).

Our studies focused on the role of firsthand experience in children's teaching, but they converge with research on how children's own experience with a task affects their willingness to imitate a model's novel action. Williamson, Meltzoff, and Markman (2008) asked 3-year-old children to complete a simple task: opening a drawer or pushing a car down a track. They manipulated whether children found it easy or difficult to perform the task assigned to them. The authors found that children were significantly more likely to imitate the model's novel method of completing the task (i.e., pushing the car down the lane using only extended index and middle fingers) if they had difficulty in completing that same task at the start of the experiment. Thus, children's prior difficulty in acquiring a skill enhanced their receptivity to a taught method (see also Williamson & Meltzoff, 2011). Our results suggest that children are also more likely to teach what they were taught when they could not easily discover this information on their own. By implication, children's imitation *and* their teaching are influenced by their own experience with a task. Knowing that a given method is not easy to discover or deploy, children are receptive to teaching and, in addition, likely to transmit what they are taught.

Turning to the issue of informational opacity, we believe that the increased transmission of the experimenter's method in Studies 1 and 3 relative to Study 2, and in Study 3 relative to Study 2, reflects differences in the opacity of the taught information relative to children's self-discovered knowledge. Furthermore, we believe that the increased transmission of taught information in Study 1 relative to Study 3 is attributable to differences in how children interpreted the opacity of the taught information. In Study 1, the experimenter's method was both hard to discover and more elaborate. The elaborate nature of the experimenter's method may have led children to infer that the goal of the teaching was conventional (i.e., to transmit a ritualized method of obtaining stickers). In contrast, in Study 3, the experimenter's method was just as simple and efficient as the child's own method. Consequently, in Study 3, children may have inferred that the teacher's instructional goal was instrumental rather than conventional. If this interpretation is correct, it would converge with recent research demonstrating that the use of conventional framing rather than instrumental framing (i.e., "this is how we do it" vs. "this is how she always does it") increases children's imitative fidelity (Legare et al., 2015). This suggests that children's inferences about the instructional goal of the teacher as well as the relative opacity of the taught method vis-à-vis children's self-discovered method may influence the information that children choose to prioritize in their own teaching.

Future research can probe these possibilities by asking children—after they have taught the naive actor—to demonstrate the *right way* to use the box and the *fastest way* to use the box. Children's subsequent demonstrations, when analyzed in relation to their spontaneous instruction, may clarify how children are interpreting what they have been taught and how this affects what they choose to teach. For example, children in Study 1 transmitted only the information they were taught. We might surmise that they would continue to demonstrate the taught method when asked to teach the right way but would demonstrate their own method when asked to teach the fastest way. This would suggest that children saw the taught information as conventional and that this influenced their decision to transmit only that information.

This raises an important question left unanswered by our study, which is the extent to which children's decisions to prioritize opaque information were deliberate and conscious choices. On the one hand, it is possible that children decided to teach a method they thought the learner would not be able to discover on his or her own *in order to* be helpful and informative. On the other hand, it is equally possible that children would not be able to articulate this rationale because they are guided in an implicit fashion by their own experience. Existing research on children's understanding of teaching and on children's actual teaching has yet to explore how reflective children are in their teaching. We know that children's understanding of teaching develops between 3 and 5 years of age (Ziv & Frye, 2004; Ziv, Solomon, & Frye, 2008), but this line of research has focused on children's understanding of the role of intentions, knowledge, and beliefs in teaching rather than on children's conception of the information being taught—its complexity and learnability. Similarly, research on how children teach—for example, children's selection of informative samples to teach concepts to a naive learner (e.g., Rhodes, Gelman, & Brickman, 2010)—has not yet established whether children's selection of such samples is based on an explicit understanding of the role of sample composition in learning and whether such an explicit understanding explains development and individual differences in children's ability to use pedagogical sampling.

Finally, although our research focused on the impact of children's learning history on *what* children chose to teach, a secondary question is whether the way in which children are taught influences *how* they then teach. We could not answer this question because the manner in which the experimenter taught (by explaining and demonstrating) is identical to the manner in which Western children would be expected to teach at this age (Strauss & Ziv, 2012; Strauss et al., 2002)—perhaps because, by the time they are 5 years of age, children have been socialized to teach according to their culture's predominantly verbal teaching style. Indeed, mothers with more years of education engage in more directed verbal instruction than mothers with fewer years of education (Levine, Levine, Schnell-Anzola, Rowe, & Dexter, 2012). This suggests that as they get older, children (and adults) increasingly model their teaching after the teaching they themselves have received. An experimental test of whether children do imitate the manner in which they are taught would require two conditions: one where the teacher is silent and only demonstrates the method and one where the teacher explains but does not demonstrate. It would then be possible to test whether children's own teaching methods mirror the methods used by their instructors.

In summary, children very often teach what they have been taught. However, when they are allowed to explore and to discover their own solutions, they are less likely to teach what they have been taught—at least when the taught method is no less obvious than their own. Thus, whereas children often transmit what they had been taught, they are especially likely to do so if they could not readily discover that method for themselves. This suggests that teachers' own learning history plays an important role in the development of cumulative culture; it ensures that teaching time is devoted to transmitting the skills that are hardest to acquire.

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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.2015.09.032.

References

Bonawitz, E., Shafto, P., Gweon, H., Goodman, N. D., Spelke, E., & Schulz, L. (2011). The double-edged sword of pedagogy: Instruction limits spontaneous exploration and discovery. *Cognition, 120*, 322–330.
Boyd, R., & Richerson, P. J. (1985). *Culture and the evolutionary process*. Chicago: University of Chicago Press.
Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences, 13*, 148–153.
Csibra, G., & Gergely, G. (2011). Natural pedagogy as evolutionary adaptation. *Philosophical Transactions of the Royal Society B: Biological Sciences, 366*, 1149–1157.

Dean, L. G., Kendal, R. L., Schapiro, S. J., Thierry, B., & Laland, K. N. (2012). Identification of the social and cognitive processes underlying human cumulative culture. *Science, 335*, 1114–1118.
Flynn, E., & Smith, K. (2012). Investigating the mechanisms of cultural acquisition: How pervasive is overimitation in adults? *Social Psychology, 43*, 185–195.
Fogarty, L., Strimling, P., & Laland, K. N. (2011). The evolution of teaching. *Evolution, 65*, 2760–2770.
Gelman, S. A., Ware, E. A., Manczak, E. M., & Graham, S. A. (2013). Children's sensitivity to the knowledge expressed in pedagogical and nonpedagogical contexts. *Developmental Psychology, 49*, 491–504.
Gweon, H., Chu, V., & Schulz, L. E. (2014). To give a fish or to teach how to fish? Children weigh costs and benefits in considering what information to transmit. In P. Bello, M. Guarini, M. McShane, & B. Scassellati (Eds.), *Proceedings of the 36th Annual Conference of the Cognitive Science Society* (pp. 559–564). Austin, TX: Cognitive Science Society.
Kenward, B. (2012). Over-imitating preschoolers believe unnecessary actions are normative and enforce their performance by a third party. *Journal of Experimental Child Psychology, 112*, 195–207.
Kenward, B., Karlsson, M., & Persson, J. (2011). Over-imitation is better explained by norm learning than by distorted causal learning. *Proceedings of the Royal Society B: Biological Sciences, 278*, 1239–1246.
Keupp, S., Behne, T., & Rakoczy, H. (2013). Why do children overimitate? Normativity is crucial. *Journal of Experimental Child Psychology, 116*, 392–406.
Legare, C. H., Wen, N. J., Herrmann, P. A., & Whitehouse, H. (2015). Imitative flexibility and the development of cultural learning. *Cognition, 142*, 351–361.
Levine, R. A., Levine, S. E., Schnell-Anzola, B., Rowe, M. L., & Dexter, E. (2012). *Literacy and mothering: How women's schooling changes the lives of the world's children*. New York: Oxford University Press.
Lyons, D. E., Damrosch, D. H., Lin, J. K., Macris, D. M., & Keil, F. C. (2011). The scope and limits of overimitation in the transmission of artefact culture. *Philosophical Transactions of the Royal Society B: Biological Sciences, 366*, 1158–1167.
McGuigan, N. (2012). The role of transmission biases in the cultural diffusion of irrelevant actions. *Journal of Comparative Psychology, 126*, 150–160.
McGuigan, N., Gladstone, D., & Cook, L. (2012). Is the cultural transmission of irrelevant tool actions in adult humans (*Homo sapiens*) best explained as the result of an evolved conformist bias? *PLoS One, 7*(12), e50863.
McGuigan, N., Makinson, J., & Whiten, A. (2011). From over-imitation to super-copying: Adults imitate causally irrelevant aspects of tool use with higher fidelity than young children. *British Journal of Psychology, 102*, 1–18.
Nielsen, M., & Tomaselli, K. (2010). Overimitation in Kalahari Bushman children and the origins of human cultural cognition. *Psychological Science, 21*, 729–736.
Rhodes, M., Gelman, S. A., & Brickman, D. (2010). Children's attention to sample composition in learning, teaching, and discovery. *Developmental Science, 13*, 421–429.
Strauss, S., & Ziv, M. (2012). Teaching is a natural cognitive ability for humans. *Mind, Brain, and Education, 6*, 186–196.
Strauss, S., Ziv, M., & Stein, A. (2002). Teaching as a natural cognition and its relations to preschoolers' developing theory of mind. *Cognitive Development, 17*, 1473–1487.
Thornton, A., & Raihani, N. J. (2008). The evolution of teaching. *Animal Behaviour, 75*, 1823–1836.
Tomasello, M. (2009). *The cultural origins of human cognition*. Cambridge, MA: Harvard University Press.
Williamson, R. A., & Meltzoff, A. N. (2011). Own and others' prior experiences influence children's imitation of causal acts. *Cognitive Development, 26*, 260–268.
Williamson, R. A., Meltzoff, A. N., & Markman, E. M. (2008). Prior experiences and perceived efficacy influence 3-year-olds' imitation. *Developmental Psychology, 44*, 275–285.
Wood, D., Wood, H., Ainsworth, S., & O'Malley, C. (1995). On becoming a tutor: Toward an ontogenetic model. *Cognition and Instruction, 13*, 565–581.
Ziv, M., & Frye, D. (2004). Children's understanding of teaching: The role of knowledge and belief. *Cognitive Development, 19*, 457–477.
Ziv, M., Solomon, A., & Frye, D. (2008). Young children's recognition of the intentionality of teaching. *Child Development, 79*, 1237–1256.