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SHORT REPORT

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Questioning supports effective transmission of knowledge and increased exploratory learning in pre-kindergarten children

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Abstract
How can education optimize transmission of knowledge while also fostering further learning? Focusing on children at the cusp of formal schooling (N = 180, age = 4.0–6.0 y), we investigate learning after direct instruction by a knowledgeable teacher, after questioning by a knowledgeable teacher, and after questioning by a naïve informant. Consistent with previous findings, instruction by a knowledgeable teacher allows effective information transmission but at the cost of exploration and further learning. Critically, we find a dual benefit for questioning by a knowledgeable teacher: Such *pedagogical questioning* both effectively transmits knowledge and fosters exploration and further learning, regardless of whether the question was directed to the child or directed to a third party and overheard by the child. These effects are not observed when the same question is asked by a naïve informant. We conclude that a teacher's choice of pedagogical method may differentially influence learning through their choices of how, and how not, to present evidence, with implications for transmission of knowledge and self-directed discovery.
A video abstract of this article can be viewed at: https://www.youtube.com/watch?v=FJXH2b65wL8

> *The true direction of the development of thinking is not from the individual to the social, but from the social to the individual … The teacher must adopt the role of facilitator not content provider.* (Lev S. Vygotsky, 1986: 36)

1 | INTRODUCTION

As Vygotsky pointed out, learning in human children depends on others: Children are surrounded by people who know more about the world than they do, and ideally teaching facilitates discovery. In education, research has explored methods of formal pedagogy and led to proposals for optimizing student outcomes in core domains of academic interest (National Research Council, 2015). In evolutionary psychology and cognitive development, researchers have explored informal pedagogy and posited species-specific mechanisms to explain the efficacy of transmission and the rate of accumulation of knowledge through generations, suggesting that sensitivity to pedagogical communications may be the key that differentiates humans from other species (Csibra, 2007; Csibra & Gergely, 2009; Tomasello, 1999). Across these disciplines, trade-offs between the methods of teaching have long been debated (Dewey, 1933; Hirsh-Pasek, Golinkoff, Berk, & Singer, 2008; Hmelo-Silver, Duncan, & Chinn, 2007; Kirschner, Sweller, & Clark, 2006; Klahr & Nigam, 2004; Piaget & Inhelder, 1969). These trade-offs include the degree to which direct instruction ensures reliable transmission of specific information, and the degree to which it limits curiosity and further learning. Unifying frameworks that explain when and why such trade-offs may arise in formal and informal pedagogy and what methods may best facilitate immediate and further learning have not been forthcoming.

Our goal in the present research is to address this long-standing issue. Specifically, we build on a previously established framework for understanding both informal and formal pedagogy as learning from a knowledgeable and helpful teacher who intentionally selects evidence (Shafto, Goodman, & Frank, 2012; Shafto, Goodman, & Griffiths, 2014). We present an empirical demonstration of the trade-off between current and further learning imposed by different approaches to teaching. We find evidence that a teaching

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method commonly employed by parents and educators—formulating to-be-learned information as a question rather than a demonstration—simultaneously achieves the benefits of direct instruction and discovery learning.

Recent research has proposed computational models of pedagogy that explain how learning may change in response to evidence selected by a knowledgeable informant whose goal is to teach (Shafto et al., 2012; Shafto et al., 2014). These models are closely related to models of language, in which learning from teaching is formalized as a problem of both weighing the evidence and explaining why the evidence was selected (Clark, 1996; Frank & Goodman, 2012; Grice, 1975; Sperber & Wilson, 1995). The core hypothesis is that learners view the teacher as purposefully choosing, as opposed to randomly sampling, evidence from among a set of candidates (Baker, Saxe, & Tenenbaum, 2009; Luce, 1959; Shafto et al., 2012). Among the testable predictions that result is the idea that a teacher's choice to not present evidence supports a learner's inference that such evidence either does not exist or is unimportant, so it need not be explored; thus, teaching by direct instruction can foster immediate learning but decrease further discovery (Bonawitz et al., 2011; Shneidman, Gweon, Schulz, & Woodward, 2016).

The model of pedagogy formalizes learning as inference about a teacher's choices, and naturally extends to generate predictions about learning from alternative pedagogical approaches. We consider one such alternative: questioning. Questioning is well studied in education and cognitive development. Educators have long advocated the use of questions as a method of eliciting learning (Barnard, 1860) and researchers have documented the relative frequency of questions in typical classrooms (Gall, 1970). Although many instances of questioning have goals other than to induce learning (Black, 2001), research suggests that larger numbers of questions are related to improved learning outcomes (Lott, 1983; Wise & Okey, 1983). Research in cognitive development suggests that questions are common in maternal speech to infants and young children (Snow, 1977) and, by arrival at preschool, children are asked and understand many different types of questions (Anselmi, Tomasello, & Acunzo, 1986; Gullo, 1981; Tyack & Ingram, 1977; Yu, Bonawitz, & Shafto, 2017).

Although commonly posed by parents and teachers and theoretically central to pedagogy, research has not yielded a strong connection between when and why questions are used, or whether and what kind of learning they are likely to elicit. Consider a teacher posing a pedagogical question, a question to which they already know the answer. For example, rather than *demonstrating* the function of a non-obvious button on a toy, a teacher instead *asks*, 'What does this button do?' From the perspective of the pedagogical model, learners reason about why the informant has selected this particular statement among the set of available possibilities including from other questions (e.g., 'What does this [nob, switch, lever] do?'; 'What other toys should we play with?') or from other statements such as direct instruction (e.g., 'This button makes the toy go'). Under the model, direct instruction leads to decreased exploration through the learner's inference about why the teacher did not choose to demonstrate more functions. When a learner is posed a question, the subject of the question conveys the knowledgeable teacher's intention to teach about that function, as with direct instruction. In addition to that, the learner would also reason about why the teacher did not choose direct instruction. That is, because direct instruction naturally constrains the space of hypotheses, the teacher's choice to not use direct instruction implies the possibility that exploration may lead to further discoveries. We thus predict that when asked a pedagogical question, the learner would both learn about the target function as would follow from direct instruction, but also explore *more broadly*. Such an inference holds even if the question is directed to another and overheard by the learner; the assumptions about the teacher trying to teach the target function without eliminating further possibilities will be the same even for an eavesdropper.

Note, however, that the content of the question is not sufficient to draw these inferences. Inherent in the learner's assessment is consideration of the knowledge state and goal of the questioner. Consider the same question ('What does this button do?') posed by a naïve informant. Although the question conveys curiosity by the informant and might therefore foster greater exploration by the learner, it does not convey information about the importance of the specific part because the naïve informant does not yet know the outcome. Thus, a question from a naïve informant does not predict increased learning about the target function.

To explore the predictions of the pedagogical question account, we conducted empirical experiments in which adults showed preschoolers a novel toy, and pointed out one target function on the toy using either a direct instruction, a pedagogical question, or a naïve question. We predicted that preschoolers' learning and exploration about the novel toy will differ based on how the information was presented to them, and they will both learn the target function and explore the toy broadly after a pedagogical question.

RESEARCH HIGHLIGHTS

- A teacher's choice of pedagogical method may differentially influence learning through their choices of how, and how not, to present evidence.
- Questioning by a knowledgeable teacher, but not an ignorant informant, is as effective in transmitting knowledge as direct instructions.
- Questioning by a knowledgeable teacher also leads to increased exploration and discovery learning compared to direct instructions.
- These effects are observed when the content of the questions and instructions are carefully controlled.

2 | EXPERIMENT 1

Experiment 1 examined the pedagogical question account with four experimental conditions. Children were introduced to a novel toy that was designed to appear to have many possible functions (Figure 1a). To compare direct instructions with pedagogical questioning, we set up conditions where a knowledgeable experimenter either told children about one function of the toy ('You push this button') or asked a question about the same function ('What does this button do?'). To compare between pedagogical and naïve questioning, we set up an additional condition in which a naïve confederate asked the same question ('What does this button do?'). To make it clear to children that this naïve question is intended to seek information rather than to teach, the confederate directed this question to the experimenter, and children overheard it. Finally, to control for the effect of overhearing, we also ran a condition in which the experimenter asked the confederate the pedagogical question, and children overheard it. We hypothesized that children who heard a pedagogical question, no matter whether it was directed to them or to a third party, will learn the target function as well as children who received direct instruction. At the same time, they will explore more broadly and discover more non-target functions than those receiving direct instruction.

2.1 | Method

2.1.1 | Participants

Participants were 120 4- and 5-year-old children (M_{age} = 5.0 y, SD = 0.6 y, range = 4.0–6.0 y). Children were recruited from preschools near Louisville, KY, and Newark, NJ, and were diverse with respect to race, ethnicity (52% white, 16% black, 16% Hispanic-Latino, 10% Asian, 6% multi-racial) and socioeconomic status. An equal number of children (n = 15 for each age group) were assigned to one of the four conditions; age was matched across conditions. Detailed information about the demographics of children in each condition can be found in Table S1. Parental consents were acquired prior to children's participation.

2.1.2 | Materials

A novel toy was created (Figure 1a) that was approximately 14″ × 7.5″ × 14.5″. In addition to several inert properties, the toy had five functional parts: a tower that lit up when a button was pushed, a knob that produced a squeaking sound when squeezed, a lady bug pin light that flashed in three different patterns when pushed, a flower magnet that moved between three different places on the toy, and a turtle hidden in a pipe that was visible through a magnifying window.

2.1.3 | Procedure

Children were individually tested in a quiet classroom in their preschool. In all conditions, the experimenter began by saying 'Today, I'm going to show you a cool toy that I have. [The confederate] has never seen my toy before and doesn't know how it works. Say, [the confederate], will you please bring out my toy? It is that one, over there.' After the confederate brought out the toy and handed over to the experimenter, the experimenter then reminded children: 'So remember, [the confederate] hasn't seen my toy before either! It is my toy and I know all about how it works!'

The next step of the experiment differed depending on which condition the child was assigned to. In the direct instruction (DI) condition (Figure 1b), the experimenter addressed the child saying, 'I'm telling you: You push this button', and pressed a button on the yellow tower, demonstrating that the button caused the tower to light up. In the pedagogical question (PQ) condition (Figure 1c), the experimenter asked the child, 'I'm asking you to think about: What does this button do?', while pointing to the button. In the pedagogical question-overheard (PQO) condition (Figure 1d), the experimenter asked the same question to the confederate, while pointing to the button. Finally, in the naive question-overheard (NQO) condition (Figure 1e), the confederate asked the experimenter, 'I was just thinking: What does this button do?', while pointing to the button.

Following this, the participant was told that it was his or her turn to play with the toy and to let the experimenter and confederate know when he or she was done. Consistent with a previous study (Bonawitz et al., 2011), if the child said that he or she was finished or if he or she stopped playing with the toy for more than 5 consecutive seconds, the experimenter asked, 'Are you done?' If the child responded in the negative, the child was left to continue to play until he or she stopped interacting with the toy a second time. The second time that the child stopped interacting with the toy for 5 consecutive seconds, the experimenter ended the experiment. At the end of the experiment, the child was presented with a small toy and a certificate of thanks.

All of the videos from the sessions were coded by one of seven research assistants blind to condition. We coded four outcome measurements: activation of the target function, total time playing, number of unique actions performed, and number of non-target functions activated (Table S2 provides details about the coding procedure and a list of unique actions being coded). Twenty percent of videos (24 out of 120) were coded by a second blind coder, and the inter-coder reliability was high for all measurements (activation of the target function: κ = 0.96; total time playing: r^2 = 1.00; number of unique actions performed: r^2 = 0.87; number of non-target functions activated: κ = 0.91).

2.1.4 | Data analysis

All data were entered and analyzed in IBM SPSS 22. Chi-square tests and logistic regressions were used to analyze binary outcomes (activation of target function), whereas planned linear contrasts and linear regressions were used to analyze continuous outcomes (total time playing, number of unique actions, and number of non-target functions). Two-tailed tests and an α level of 0.05 were used for all tests.

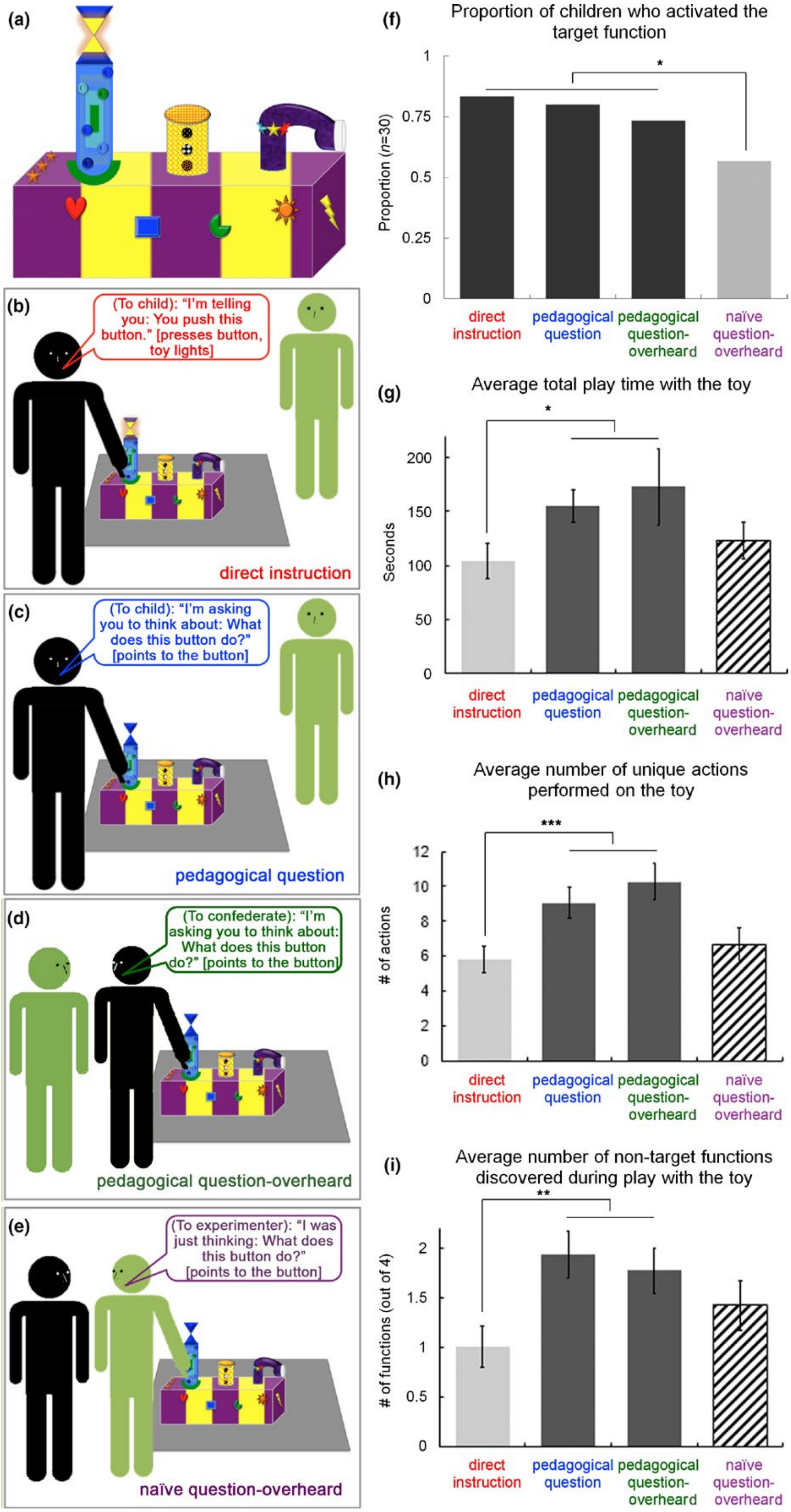

FIGURE 1 Stimuli (a), procedure (b–e), and results (f–i) of Experiment 1. Children were more likely to activate the target function following direct instructions or pedagogical questions than following naïve questions (f); and they explored more and discovered more non-target functions following pedagogical questions than following direct instructions (g-i). $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$

2.2 | Results

Age was not a significant predictor for any of the four outcome measurements (activation of target function: Wald = 2.56, $p = 0.110$; other three measurements: $rs < 0.05$, $ps > 0.250$). Therefore, the two age groups were collapsed for all analyses, and age was controlled for in the regression analyses.

2.2.1 | Transmission of knowledge

Questioning by a knowledgeable informant was predicted to achieve effective transmission of knowledge like direct instruction, and in contrast with naïve questioning. Our results confirmed this hypothesis (Figure 1f): Questions asked by a knowledgeable informant (both those directed to the child and to the confederate) and direct instruction resulted in a greater proportion of children activating the target function than in response to naïve questioning (DI: 24/30; PQ: 25/30; PQO: 22/30; NQO: 17/30; DI vs. PQ vs. PQO, $\chi^2(2) = 0.93$, $p > 0.250$; DI, PQ, and PQO combined vs. NQO, $\chi^2(1) = 5.68$, $p = .017$). This result held when age was controlled for: Naïve questioning, as compared to other formats of instructions, negatively predicted the likelihood of target function activation when age was entered as a covariate ($b = -1.09$, 95% CI [−1.98, −0.19], Wald = 5.63, $p = .018$). Whereas children in all conditions played with the tower that had the target function (DI: 27/30; PQ: 28/30; PQO: 28/30; NQO: 28/30), naïve questions resulted in greater proportions of children who played with the tower without activating the target function (DI: 2/27, PQ: 3/28, PQO: 3/28; NQO: 11/28; DI vs. PQ vs. PQO, $\chi^2(2) = 0.23$, $p > .250$; DI, PQ, and PQO combined vs. NQO, $\chi^2(1) = 12.97$, $p < .001$). This suggests that pedagogical questions were interpreted differently from naïve questions: Questions asked by a knowledgeable informant resulted in no difference from direct instruction in whether children attended to the target part, but naïve questions did diminish children's ability to discover the target function.

2.2.2 | Exploration and further learning

Questions by a knowledgeable teacher were found to foster effective information transfer; however, they were predicted to do so while also encouraging exploration, unlike direct instruction. We tested this hypothesis using planned linear contrasts between direct instruction (assigned weight of +2), pedagogical question (assigned weight of −1), and pedagogical question-overheard (assigned weight of −1). As shown in Figure 1g–l, compared to direct instruction, children played longer in response to pedagogical questions (M_{DI} = 104s, SD_{DI} = 87s, M_{PQ} = 155s, SD_{PQ} = 81s, M_{PQO} = 173s;[1] SD_{PQO} = 190s; $t(68.2) = 2.45$, $p = 0.017$), attempted more unique actions ($M_{DI} = 5.80$, $SD_{DI} = 4.29$, $M_{PQ} = 9.07$, $SD_{PQ} = 5.00$, $M_{PQO} = 10.27$, $SD_{PQO} = 5.87$; $t(87) = 3.39$, $p = 0.001$), and discovered more built-in, non-target functions ($M_{DI} = 1.00$, $SD_{DI} = 1.14$, $M_{PQ} = 1.93$, $SD_{PQ} = 1.31$, $M_{PQO} = 1.77$, $SD_{PQO} = 1.28$; $t(87) = 3.05$, $p = 0.003$), suggesting that pedagogical questioning leads to increased exploration and further learning relative to direct instruction. Notably, the differences in exploration and discovery learning cannot be fully explained by the increased play time itself: When we coded the first minute of children's play (79% of all children played longer than 1 minute), we still observed the differences in unique actions attempted ($M_{DI} = 2.17$, $SD_{DI} = 1.56$, $M_{PQ} = 3.23$, $SD_{PQ} = 2.46$, $M_{PQO} = 4.53$, $SD_{PQO} = 2.80$; $t(84.0) = 3.87$, $p < 0.001$) and non-target functions discovered ($M_{DI} = 0.55$, $SD_{DI} = 0.81$, $M_{PQ} = 1.27$, $SD_{PQ} = 0.98$, $M_{PQO} = 1.00$, $SD_{PQO} = 0.95$; $t(84.0) = 2.85$, $p = 0.006$). All these results held after age was controlled for: Pedagogical questioning (including overheard), as compared to direct instruction, positively predicted total time playing ($b = 61.8$, 95% CI [5.1, 118.5], $t = 2.14$, $p = 0.036$), total number of unique actions ($b = 3.86$, 95% CI [1.61, 6.10], $t = 3.37$, $p = 0.001$), total number of non-target functions ($b = 0.846$, 95% CI [0.299, 1.393], $t = 3.03$, $p = 0.003$), number of unique actions in the first minute ($b = 1.73$, 95% CI [0.67, 2.79], $t = 3.23$, $p = 0.002$), and number of non-target functions in the first minute ($b = 0.583$, 95% CI [0.172, 0.993], $t = 2.82$, $p = 0.006$). Pedagogical questioning (including overheard) also led to increased unique actions compared to naïve questioning ($M_{PQ} = 9.07$, $SD_{PQ} = 5.00$, $M_{PQO} = 10.27$, $SD_{PQO} = 5.87$, $M_{NQ} = 6.62$, $SD_{NQ} = 5.37$; planned linear contrast: $t(87) = 3.39$, $p = 0.001$). However, differences in total play time and number of non-target functions discovered were non-significant ($ts < 1.5$, $ps > 0.1$).

2.3 | Discussion

Experiment 1 examined the effect of pedagogical questioning on children's learning and exploration of a novel toy. Results suggested that pedagogical questioning was as effective as direct instruction in transferring information about the target function, while at the same time encouraged further exploration of the toy and discovery of non-target functions. These effects were not observed when the question was asked by a naïve adult who knew nothing about the toy—naïve questioning was shown to be less effective in transferring information compared to the other approaches.

One alternative explanation for differences between the pedagogical question and the naïve question condition is that children may attend differently to questions directed to them as compared to questions that were merely overheard. However, we controlled for this by virtue of the pedagogical question-overheard condition, which ruled out this alternative explanation for our data. Furthermore, the condition differences cannot be attributed to children's age or the number of experimenters present during demonstration, as these factors were controlled for between conditions. We suggest that the differences across conditions are the result of different inferences about how adults presented information to them: While children inferred an intention to teach for both the direct instruction and the pedagogical question (but not the naïve question), they viewed the direct instruction, but not the pedagogical question, as constraining their further exploration of the toy.

Several possible mechanisms underlie these differences. Our preferred explanation, built on Shafto et al. (2012), is that direct instruction constrains the space of hypotheses because children assume that a knowledgeable and helpful teacher would present the whole truth and not leave out useful information. Questioning, on the other hand, presents an alternative teaching method that does not necessarily imply that constraint due to their open form. But two other explanations also warrant examination: First, the imperative tone used in our direct instruction procedure ('I'm telling you: You push this button') may have caused children to assume that they were only supposed to learn about the target function. Second, the fact that the experimenter demonstrated the target function in the direct instruction condition but not the pedagogical question conditions may have led to different inferences about how the toy works. Experiment 2 was designed to address these alternative explanations. In addition, due to logistic reasons Experiment 1 was conducted in two different locations (Louisville, KY and Newark, NJ) with different experimenters, and the number of participants assigned to each condition was unequal between locations (Table S1). To address this potential confound, in Experiment 2 all data were collected by the same experimenters in the same location (Newark, NJ), and were coded by the same coders.

3 | EXPERIMENT 2

In Experiment 2, we carefully matched the language use in the direct instruction and pedagogical question conditions. Also, in both conditions the experimenter pointed to the button but did not activate it. This allows us to rule out deflationary explanations for differences between the pedagogical question and direct instruction conditions of Experiment 1.

3.1 | Method

3.1.1 | Participants

Participants were 60 4- and 5-year-old children (M_{age} = 4.9 y, *SD* = 0.5 y, range = 4.0–6.0 y) recruited from preschools and a local zoo near Newark, NJ. An equal number of children (*n* = 15 for each age group) were assigned to one of the two conditions. Testing sites were also balanced between conditions.

3.1.2 | Procedure

The procedure was identical to Experiment 1 except for how the experimenter addressed the child after getting the toy from the confederate. In the direct instruction condition, the experimenter said, 'Push this button to see what happens', while pointing to the button. In the pedagogical question condition, the experimenter said, 'What happens if you push this button?', while pointing to the button.

All of the videos from the sessions were coded by two independent coders who were blind to condition. The first coder coded all videos for the four outcome measurements; the second coder randomly selected 30% of videos (18 out of 60) to code. Inter-coder reliability was high for all measurements (activation of the target function: κ = 1; total time playing: r^2 = 1.00; number of unique actions performed: r^2 = 0.90; number of non-target functions activated: κ = 0.71).

3.1.3 | Data analysis

Results from Experiment 1 suggested that all between-condition differences for exploration and further learning were in one direction (pedagogical question was greater than direct instruction). Because Experiment 2 aimed to replicate these differences for which the directions were prespecified (i.e., H_0: pedagogical question equals direct instruction; H_1: pedagogical question is greater than direct instruction), we used one-tailed tests with an α level of 0.05.

3.2 | Results and discussion

Pedagogical questions and direct instruction achieved similar effectiveness in transmitting knowledge: Similar proportions of children in the two conditions activated the target function (DI: 26/30; PQ: 30/30; $\chi^2(1) = 2.41$, $p = 0.12$). On the other hand, children explored more after a pedagogical question compared to direct instruction: They played longer (M_{PQ} = 224s,[2] SD_{PQ} = 207, M_{DI} = 136s, SD_{DI} = 136, $t(58) = 1.954$, $p = 0.028$), attempted more unique actions (M_{PQ} = 9.10, SD_{PQ} = 4.61, M_{DI} = 6.80, SD_{DI} = 4.66, $t(58) = 1.921$, $p = 0.030$), and discovered more built-in, non-target functions (M_{PQ} = 2.07, SD_{PQ} = 1.31, M_{DI} = 1.43, SD_{DI} = 1.37; $t(58) = 1.839$, $p = 0.036$).

Notably, in this experiment the pedagogical question and direct instruction conditions were closely matched, so that differences between conditions could not be attributed to procedural differences. These results provided a replication of Experiment 1, and showed that children attend to how information was presented to them, and explore more after pedagogical questions as compared to direct instructions.

4 | GENERAL DISCUSSION

Consistent with models that formalize pedagogy as learning from knowledgeable and helpful teachers, direct instruction leads to effective transfer of knowledge at the cost of decreased exploration and further learning. However, rephrased as a question, the same evidence can achieve comparable knowledge transmission, while also encouraging exploration and further learning, but only if the informant is knowledgeable. We conclude that a teacher's choice of pedagogical method may differentially influence learning by communicating social information about the teacher through their choices of how, and how not, to present evidence.

Two experiments have shown that children learned about a target function of a novel toy both when the function was pointed out to them through a question or an instruction. However, they explored more and discovered more non-target functions after a question compared to an instruction, even if the content of the question and instruction was carefully matched. Based on previous work on informal pedagogy (Csibra & Gergely, 2009; Shafto et al., 2012), we suggest that children reason about the informants' selection of teaching method, and use that inference to guide their own learning and exploration. Notably, we do not assume this inferential process to be explicit, which may require higher-order theory of mind and counterfactual reasoning. Instead, children's learning from an adult–child interaction has been shown to be influenced by the presence or absence of subtle pedagogical cues (e.g., joint attention and child-directed speech) from early in infancy (Brugger, Lariviere, Mumme, & Bushnell, 2007; Butler & Markman, 2014; Southgate, Chevallier, & Csibra, 2009), and similar inferential capacities may underlie their learning from different teaching formats.

Our findings raise new questions regarding the mechanisms underlying children's inferences following questions versus instructions. One potential explanation concerns whether the language indicates closure. Direct instruction could indicate a closure, which may elicit a stronger inference that the evidence being taught is exclusive (i.e., what was not shown did not exist or was not important). In contrast, pedagogical questions are often open-ended and thus may leave open other possibilities. Asking the child 'what [they think] the button does' or 'what [they think] would happen' gives a measure of control back to the child who may think, 'Hey, I'm in charge of discovering how this works', which opens avenues for exploration. Future research is needed to empirically explore theses possible explanations, as well as to formalize the distinction between questions and instructions in the computational models of informal pedagogy.

Our results provide in-principle support for concerns in the popular press (Newsweek Staff, 2006; Strauss, 2014) and in science (Amrein & Berliner, 2002; Hirsh-Pasek, Golinkoff, & Eyer, 2004; Sacks, 2000) that fact-centered approaches driven by a test-focused culture in education may have long-term costs for learning. Our study focused on children who are at the cusp of school age, to emphasize that children, from the beginning of their educational experiences, are reasoning about how and why teachers make the pedagogical choices that they do. These results are consistent with previous findings suggesting that although direct instruction has measurable immediate effects, it may come at the cost of further learning if framed in a particular way. Motivated by a formal model of pedagogy, we introduce an alternative method, questioning by teachers, which appears to have the same immediate benefits to learning as direct instruction, but without the costs for further discovery.

We show that pedagogical questions strike an appropriate balance for children of preschool age in this particular learning instance. However, we do not know whether varied pedagogical approaches lead to differences in long-term consolidation of information. Furthermore, learning at later ages and on timescales more in accordance with those observed in education implicate a broader array of cognitive functions, and therefore warrant individualized consideration. Closer coupling between empirical tests of theories that span cognitive development and education, such as our approach here, has the potential to shed light on how results from one domain may inform theory and practice in the other.

We see two main contributions of this work. First, these findings inform our understanding of how children at the cusp of formal schooling learn, and therefore also inform which educational techniques may most effectively serve our educational goals. Because direct instruction can come at a cost in further discovery-based learning, our evidence suggests that this method should be used sparingly in educational practices with young children. Pedagogical questions, on the other hand, may be as effective at eliciting learning, but without the potential for negative implications. Second, our results provide support for a unifying framework that relates foundational theories of social learning in cognitive development to core questions and techniques used in education. This has particular promise for guiding the development of a theoretically motivated, computationally precise framework of how the knowledgeable and intentional selection of evidence in teaching may affect learning both positively and negatively. We believe this to be a promising path toward bringing research in cognitive development to bear on education and vice versa.

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ENDNOTES

[1] One child in the pedagogical question-overheard condition explored for 918 seconds, which was more than three standard deviations above the average. Excluding this child did not cause any qualitative change in results: For transmission of knowledge, pedagogical questioning and direct instruction still resulted in a greater proportion of children activating the target function than in response to naïve questioning, $\chi^2(1) = 5.52$, $p = .02$. For exploration and further learning, children still played longer in response to pedagogical questions than to direct instruction ($t(115) = 2.13$, $p = .04$), attempted more unique actions ($t(115) = 3.33$, $p = .001$), and discovered more built-in, non-target functions ($t(115) = 2.86$, $p = .005$).

[2] One child in the pedagogical question condition explored for 899 seconds, which was more than three standard deviations above the average. Excluding this child did not cause any qualitative change in results: For transmission of knowledge, there was still no difference between pedagogical questioning and direct instruction ($\chi^2(1) = 2.31$, $p = .12$). For exploration and further learning, children still played longer in response to pedagogical questions than to direct instruction ($t(57) = 1.65$, $p = .053$), attempted more unique actions ($t(57) = 1.81$, $p = .038$), and discovered more built-in, non-target functions ($t(57) = 1.72$, $p = .045$).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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