CHILD DEVELOPMENT

Child Development, xxxx 2021, Volume 00, Number 0, Pages 1–16

An Illusion of Self-Sufficiency for Learning About Artifacts in Scaffolded Learners, But Not Observers

Emory Richardson
Yale University

Mark Sheskin
Yale University and Minerva Schools at KGI

Frank C. Keil
Yale University

Two studies ask whether scaffolded children (n = 243, 5–6 years and 9–10 years) recognize that assistance is needed to learn to use complex artifacts. In Study 1, children were asked to learn to use a toy pantograph. While children recognized the need for assistance for indirect knowledge, 70% of scaffolded children claimed that they would have learned to use the artifact without assistance, even though 0% of children actually succeeded without assistance. In Study 2, this illusion of self-sufficiency was significantly attenuated when observing another learner being scaffolded. Learners may fail to appreciate artifacts' opacity because self-directed exploration can be partially informative, such that learning to use artifacts is typically scaffolded instead of taught explicitly.

If an ancestor 100 generations removed appeared in your kitchen, what would they be able to figure out on their own and what would they need your help to understand? In some cases, simple heuristics about informational access can help us delineate indirect and direct knowledge. Some kinds of knowledge, like historical facts, object labels, and scientific minutiae, are only accessible through other people. Other kinds of knowledge, like the basic physical characteristics of objects and simple causal affordances, can easily be acquired through observation and random discovery, even if there is no one available to learn from.

Here we focus on a third kind of knowledge, shared by virtually every mature member of a culture: the use of that culture's everyday artifacts, such as telephones and blenders. Like much of what we consider common knowledge, the use of artifacts is acquired through a combination of pedagogy and the learner's own unassisted discovery. The massive stores of common knowledge acquired by adulthood suggest that the balance of pedagogy and unassisted discovery must be fairly efficient; indeed, sociocultural theories of learning emphasize that learning is a *collaborative* process between learner and expert, rather than an assembly line construction (Rogoff, 1990, 2014; Tomasello, Kruger, & Ratner, 1993; Vygotsky, 1978; Wood, Bruner, & Ross, 1976). Here, we present evidence suggesting that even as children begin to recognize the difference between indirectly and directly accessible knowledge, collaborative learning may mask the extent to which pedagogical support is *necessary* to learn to use many artifacts.

Do Children Know When Unassisted Discovery is Insufficient?

Young learners of course readily ask for help when they feel they need it; and help-seeking is modulated by the child's skill level and the difficulty of the task, suggesting that children are not asking for assistance until they are actually uncertain of what to do next (Vredenburgh & Kushnir, 2016). Nevertheless, early in development, children's verbal reports underestimate the need for instruction. Four-year-olds claim that a child who wants to learn a song will learn even if the child neither sings along with the teacher nor pays attention to the singing (Sobel, Li, & Corriveau, 2007). Five-year-olds' explanations of how a child learned

For helpful conversations, we thank the members of the Yale Cognition and Development Lab. For assistance with data collection, we thank Garrett Greeley, Portage Central Elementary, and the Stepping Stones and Peabody Museums. This project was funded by NSF grant #DRL1561143 awarded to Frank C. Keil.

 0009-3920/2021/xxxx-xxxx
DOI: 10.1111/cdev.13506

to use a toy focus overwhelmingly on the role of self-directed exploration, even when describing vignettes in which children learned exclusively by instruction (Sobel & Letourneau, 2018). Thus, one possibility is that young children decide when to seek help simply by monitoring their own uncertainty during the learning process, without inferring more generally that help may actually be *necessary* to learn that thing.

However, preschoolers can predict when help may be needed if the difficulty of a task is sufficiently clear to them. Given experience with one difficult-to-solve puzzle box and asked whether they would need help to solve another, perceptually distinct, puzzle box, preschoolers do predict that they will need help. Despite this, when given a choice between seeing the experimenter solve the new puzzle box for them and trying to solve it unassisted, preschoolers choose unassisted exploration—and increasingly so with age, despite uniformly failing to open the first box without help (Was & Warneken, 2017). Thus, children's explicit predictions may not always guide their behavior. When 5- to 7-year-olds learn how to use a difficult-to-figure-out toy (with seven buttons, two of which must be pressed simultaneously) and an easy-to-figure-out toy (with one large button to press), they subsequently recommend teaching a naive learner the more complex toy over the simpler toy. Importantly, they do this even if they are only *shown* how to use the toy, rather than figuring it out mostly for themselves (Bridgers, Jara-Ettinger, & Gweon, 2020). Taken together, these studies suggest a second possibility for how children understand the need for pedagogical support: by the early school years, children can explicitly infer when help is *more* or *less* important not only by referencing the difficulty of their own learning experience, but also by simulating the learning process that would allow a naive learner to discover the artifact's function.

Evidence for children's ability to evaluate the importance of pedagogical support by simulating learning costs must come with an important caveat. Frequently, artifacts are not simply "*more difficult*" or "*less difficult*" for an unassisted learner to figure out. The same division of cognitive and physical labor that "ratchets up" the specialization and complexity of modern artifacts also supports our ability to understand and learn about those artifacts (Csibra & Gergely, 2006, 2011; Tennie, Call, & Tomasello, 2009). As a result of this specialization, modern artifacts are frequently *"causally and teleologically opaque"*—in other words, they are *impossible* to learn to use without assistance, even for adults (see section "When is Independent Learning Insufficient" for discussion). Perhaps surprisingly, children and adults are unaware of how shallow their understanding of artifacts really is until they are asked to give a step-by-step, mechanistic explanation of how artifacts work (Lawson, 2006; Mills & Keil, 2004; Rozenblit & Keil, 2002). Yet, we are not wholly unaware of artifact complexity, nor are we unaware that some kinds of knowledge are typically learned from other people. Children and adults make consistent judgments of artifact complexity, though the basis for these judgments shifts across development (Ahl, Amir, & Keil, 2020; Kominsky, Zamm, & Keil, 2017). Rather, we argue, the problem is twofold.

First, our capacity for causal reasoning does allow us to discover some affordances in most artifacts, particularly as we learn more about the design features commonly reused in our culture's artifacts (see "What Can We Learn Alone?"), and these discoveries may encourage a sense of self-sufficiency. Second, because we learn to use artifacts through a collaborative process that involves both independent reasoning and pedagogical support, we may not fully appreciate the extent to which our own ability to reason about artifacts' purpose and causal functioning is inadequate (see sections "When is Independent Learning Insufficient" and "What Makes the Boundary Between Learning Alone and Learning From Others Unclear?"). Consequently, children's judgments about their own learning capacity may reflect the success of their own learning experience, while neglecting the importance of expert assistance (Study 1). Diminishing that feeling of self-sufficient discovery by removing the self-directed exploration may prompt children to evaluate the limits of individual learning differently—for example, by considering the complexity of the learning process, or the amount of expert assistance provided (Study 2). We present evidence that the illusion of self-sufficiency is not simply a failure of source-monitoring, general overconfidence, or egocentrism, nor does the illusion appear when *nothing* could be learned through self-directed exploration—for example, object labels and historical facts. Thus, the illusion may be specific to those forms of knowledge that are acquired through a combination of exploration and pedagogical scaffolding, such as the use of complex artifacts.

What Can We Learn Alone?

Consider what we *can* learn unaided. Tennie and colleagues (Reindl, Bandini, & Tennie, 2018; Tennie et al., 2009) propose that all species have a "zone of latent solutions" (ZLS): A set of mechanical reasoning strategies that can be applied to novel problems without need of social learning. For example, children ages 2- to 3.5-year old spontaneously infer the function of the perforating, scooping, and hammering tools great apes use in the wild (Reindl, Beck, Apperly, & Tennie, 2016), suggesting untutored competence in basic physical reasoning. However, the ability to learn from direct instruction, imitation, and guided exploration allows us to acquire strategies *not* in our ZLS (Lyons, Damrosch, Lin, Macris, & Keil, 2011; Tennie et al., 2009), which can in turn enable further independent learning.

Learners may even be able to figure out the use of some artifacts without guidance simply because the artifacts are sufficiently simple and self-contained that even random exploration produces a recognizable goal state. For example, a learner could press the button on a flashlight accidentally: The immediate appearance of the light reinforces the connection between pressing the button and the goal state it enables. If the learner recognizes the value of a light-producing object, that immediate reinforcement enables straightforward associative learning. However, children's unguided exploration is *not* random; it is hypothesis-driven (Gopnik, 2012), and children update their hypotheses using evidence generated by their interventions (Bonawitz, van Schijndel, Friel, & Schulz, 2012; Schulz, Gopnik, & Glymour, 2007).

Additionally, a culture's artifacts frequently share many design principles, which may enable learners to generalize function from features in previously encountered artifacts to otherwise novel artifacts (Sim & Xu, 2017). Regularities in artifact design are not incidental: artifact designers reuse their culture's solutions to common design problems (examples from industrialized countries include buttons, handles, "swipe functions," etc.), in part because of the physical laws governing artifacts' functions (one does not make hand shears with 10-foot handles, nor with dull blades), but also in order to make them intuitive for users. While the function of a common design feature such as a button or handle may not be part of our ZLS, they may allow learners already familiar with them to infer the use of an otherwise novel artifact (Magid, Sheskin, & Schulz, 2015; Walker, Rett, & Bonawitz, 2020). However, the reuse of particular design features in a culture's artifacts may also make them appear more transparent than they are; the presence of a button or a handle may feel suggestive, but it is no guarantee that using the artifact is as simple as pressing the button or gripping the handle. As we will argue (see "When is Independent Learning Insufficient" and "What Makes the Boundary Between Learning Alone and Learning From Others Unclear?"), the suggestiveness of these features may make it particularly difficult for learners to retrospectively recognize what they *would have* discovered themselves if the solution is ultimately suggested by a partner.

When Is Independent Learning Insufficient?

In many cases, the goal state is not the result of a single action like pressing a button to turn on a flashlight. Rather, the user must execute a specific sequence of actions, each of which is only an enabling condition for the ultimate goal state, rather than a sufficient cause in itself; for example, a telephone only functions if a valid sequence of numbers is dialed in a particular way. Other examples could obviously be chosen; the point we want to illustrate by these examples is that as the number of enabling conditions increases, the odds of unassisted discovery decrease (and mistakes can have serious consequences). Because human technology frequently relies on executing an ordered series of actions to achieve intermediate goals (or enabling conditions) which themselves have no intrinsic value, acquiring the use of such technology requires pedagogical support. This has led to extensive discussions of the role of pedagogy and recursive teleology in acquiring the use of artifacts, (Csibra & Gergely, 2006, 2011; Gergely & Csibra, 2006; Lyons, 2008). However, even with the most complex artifacts, some things *can* be learned without pedagogical support. Because even complex artifacts are composed of simpler, discrete mechanisms, unguided exploration may still be informative. In the case of the telephone, for example, one might discover the effect of particular buttons; nevertheless, pedagogy would be required to learn how to actually place a call.

What Makes the Boundary Between Learning Alone and Learning From Others Unclear?

Sociocultural theories of learning suggest that working together with a more expert partner allows learners to more effectively recode their partner's knowledge as their own (Rogoff, 1990; Tomasello et al., 1993). The scaffolding concept in particular (Vygotsky, 1978; Wood et al., 1976) has been applied to a variety of pedagogical approaches and domains, but most approaches exhibit three central features: providing learners with a *simplified and* *structured* learning environment, providing cognitive and emotional assistance in the form of direction and encouragement *contingent on the learners' needs* and actions, and gradually *transferring responsibility* to the learner (Boblett, 2012; Mermelshtine, 2017). For example, children across very different cultures may be allowed opportunities to observe experts and other learners using artifacts in everyday contexts (Legare, 2017; Silva, Correa-Chávez, & Rogoff, 2010), be encouraged to "pitch in" to group or dyadic activities and thus learn through joint-action with a knowledgeable partner (Rogoff, 2014), and only be given more specific guidance contingently on performance (Kärtner et al., 2008; Little, Carver, & Legare, 2016). While scaffolding can be a highly effective way to learn, scaffolding may make it challenging to distinguish between individual learning and scaffolded learning in two ways.

One challenge is simply recalling the source of information: did I learn by myself, or with help? Some sociocultural theorists have argued that some of children's source-monitoring failures in collaborative contexts are actually an index of children's successful learning. When working together with a partner toward a joint goal, errors in preschoolers' source-memory exhibit an "I-did-it" bias: children are more likely to claim credit for a partner's contribution than credit a partner for their own contribution. However, children who exhibit a stronger "I-did-it" bias perform better when tested afterward as individuals (Ratner, Foley, & Gimpert, 2002; Sommerville & Hammond, 2007). Importantly, not all forms of working together have an equal impact on the I-did-it bias. The bias is stronger when children are more integrated into the activity in ways typical of a scaffolded learning environment, such as turn-taking (Foley, Passalacqua, & Ratner, 1993, Exp 4), jointly planning next steps (Ratner et al., 2002, Exp 2), or observing an adult's activity. The bias is particularly strong if the child is able to imagine completing a step themselves, or is able to *anticipate* the adult's next step (Foley, Ratner, & House, 2002; Sommerville & Hammond, 2007). The potential to anticipate a partner's contribution, which is crucial to joint-action, may also play a central role in source-monitoring errors even in adults (Barber, Franklin, Naka, & Yoshimura, 2010; Foley, Foley, Durley, & Maitner, 2006; Landau & Marsh, 1997). We note that recognizable design features in artifacts may allow learners to feel as though they were already considering an action suggested by a partner. For example, if a learner tries a button and then a lever, and the partner suggests trying the two simultaneously, the learner may be less likely to credit the partner for the idea than if the partner had pointed out an unknown feature. Thus, learning to use an artifact through a combination of self-directed causal reasoning and intermittent expert scaffolding may make it difficult to track expert contributions.

The ability to anticipate a partner's contributions in collaborative learning approaches like scaffolding raises a second challenge: making judgments about individual *capacities*. Even if some information was acquired from someone else, *could* it have been acquired directly? In some cases, metacognitive judgments can provide a clear criterion for distinguishing one's own contributions from a partner's even when the source memory is unreliable (Johnson, Hashtroudi, & Lindsay, 1993). For example, even young children are confident that one could *not* learn the name of a historical figure without assistance, but that one *could* learn that thunder and lightning co-occur without assistance (Lockhart, Goddu, Smith, & Keil, 2016). However, learning to use artifacts is not so clear cut: it is not exclusively learned through pedagogy, nor accessible without pedagogy. Thus, even if a learner accurately recalls that their partner suggested trying the button and lever simultaneously, the learner may believe that they "would have tried it" even without the partner's input.

The Present Work

We asked whether learning to use an artifact through scaffolded exploration would induce a specific illusion of self-sufficiency. Specifically, Study 1 was designed as a confirmatory test of the prediction that, relative to a baseline success rate, scaffolded children would believe that they *could have learned* to use artifact without help, despite recognizing that (a) they *had been* helped, (b) some kinds of knowledge, such as historical facts and object labels, *are* inaccessible without pedagogy, and that (c) in other cases, they *had* required assistance to acquire a skill. We chose to test two age groups (ages 5–6 and 9–10), in order to further reduce the chance that children's responses could be explained merely as failures of source-monitoring or egocentric knowledge attributions—which both decrease dramatically between the ages of 4–6 (Drummey & Newcombe, 2002; Kloo, Rohwer, & Perner, 2017)—or as failures of counterfactual thinking, which appears to be present from age 4, but may continue to mature until late childhood (Kominsky et al., 2019; Nyhout & Ganea, 2019; Rafetseder & Perner, 2018). Study 2 was designed as a confirmatory test of the prediction that the illusion of self-sufficiency for artifacts would be reduced when taking a 3rd person perspective. Hypotheses for each question children were asked in both studies were confirmatory, but were only preregistered for Study 2.

In a preliminary study (see Supporting Information), we confirmed that the children were unable to learn to use the artifact without scaffolding. Of twenty-three 5- and 6-year-olds and twenty 9- and 10-year-olds, none succeeded. These children were simply given the artifact, told the function, and asked to learn to use it. In order to maximize their chances of success, children who seemed to give up quickly were encouraged to keep trying as many as three times. Thus, strictly speaking, this procedure included two forms of scaffolding: children were told the artifact's function, and given emotional support. As noted earlier, the function of an artifact may frequently be impossible for children to discover without assistance, and may not be realistic to expect within an experimental session; indeed, even in developmental studies of "free play," which use intentionally simplified artifacts, the function is always demonstrated to children (e.g., Sim & Xu, 2017). However, these were the only two forms of assistance the child was given; children's exploration was wholly unguided. Hence, for the sake of brevity and lexical clarity, we refer to these children as "unscaffolded." This formed a baseline comparison for children's claims of success in Studies 1 and 2.

Study 1: First Person Sensitivity to Scaffolding

In Study 1, children were scaffolded as they explored a toy pantograph that carves letters and shapes into crayons. Children were then asked whether they could have learned to use the machine without scaffolding. Children were also asked several questions to test their ability to distinguish between direct and indirect knowledge, identify the source of their knowledge, and admit to needing help in other cases.

Method

Participants

Forty-two children ages 5–6 ($M_{age} = 5.50$) and forty-five children ages 9–10 ($M_{age} = 9.51$), were recruited from museums in the northeastern United States in summer 2018. We did not collect information about race or SES, but given the demographic profiles of the area, we believe that most participants came from middle-class families. Seven children were excluded from analysis; four (age 10) for recognizing the crayon carver and knowing either the function or name, two (ages 6 and 10) for experimenter error, and one (age 5) for becoming uncooperative before answering the test questions. Thus, 40 younger and 40 older children (44% girls) participated in Study 1. Children were tested at a table in a quiet corner of the museum, with a tall partition preventing other children from seeing the machine in use before participating themselves. Parents were asked to stand discretely off to the side if they wished to observe.

Materials

Children were given a Crayola™ Crayon Carver, an electrically powered plastic toy marketed to children 6 and older that allows children to carve letters and shapes into crayons. A plastic arm based on the pantograph principle manipulates a stylus and carving needle, allowing the user to carve letters into crayons by tracing with the stylus into stencils. The stencil letters are held in place while tracing by fitting them into a peg-board at the front of the machine. In order to successfully trace, a plastic cap must be put on each end of a crayon to hold the crayon stable within a spring-loaded vice under the carving needle, and the power switch must be in the "on" position. If the crayon is not properly situated in the vice, or if the lid is open, a safety switch will prevent the power from turning on even if the power switch is in the "on" position. When the crayon is properly situated and the lid is closed, the pantograph arm can be used to trace in the stencils, producing a carving in the crayon.

Introductory Phase Scaffolding

The scaffolded group first observed the experimenter interacting with the machine in the introductory phase; however, the experimenter did not provide the step-by-step demonstration typical of direct instruction. Rather, the introductory scaffolding accomplished two goals: first, the experimenter's interaction with the machine was intended to simulate what a child might observe about artifacts in their daily lives. Second, the introduction motivated younger children to explore the machine independently so that additional scaffolding could be provided contingently, without resorting to direct instruction.

The machine was presented to children with the power switch in the "on" position, and a carved crayon and stencils already in place, as though another child had just used it. The experimenter stated the machine's function and briefly demonstrated how to use the stylus to trace into a stencil, conspicuously turning off the power as though surprised the power was on. Next, the experimenter pointed out the stencils and the other child's initials carved into the crayon. Then, the experimenter retrieved stencils with the participating child's initials from a built-in shelf on the machine, showed them to the child, and placed them on the machine in full view. Next, the experimenter showed the child a fresh crayon they could use, and replaced it in the holder on the machine. Then, as the child watched, the experimenter removed the crayon from the vice slowly and deliberately, and placed both the crayon and the plastic caps in front of the child. Finally, the experimenter explained the task to the child: to figure out how to use the machine to write their initials into the crayon. The experimenter then asked the child to "spend a little bit of time thinking about how to use the machine, *without* using your hands," and gave them 15 s to look over the machine before starting to explore it.

Exploration Phase Scaffolding

During the self-directed exploration period, children had 7 min to figure out how to use the machine to carve their initials into a crayon. During this phase, the experimenter's scaffolding was contingent on the child's actions, as might occur when a child is "pitching in" to an adult activity. Because the child had seen the machine in the "ready-to-use" state and the experimenter had already pointed out each individual feature while disassembling it during the introductory phase, reassembly should have been a relatively straightforward task: Hence, if children manipulated a part of the machine "improperly" for more than ~10 s, the experimenter scaffolded the child by asking a leading question about what they were missing (e.g., "is the power on?"). Because scaffolding is intrinsically contingent on the child's activity, the number, kind, and timing of hints could not be identical for all children. However, the protocol was standardized as much as possible.

The experimenter could give seven basic kinds of hints (one for each step in the procedure), with a standard phrasing, and one nonstandard hint (to allow for potential idiosyncratic errors not predictable from piloting). Each hint could be given as many as five times, so that if a child abandoned a strategy before completing the next step, the experimenter could give the hint again when the child returned to that step. Hints could also be repeated immediately as many as three times if the child was so engrossed in the task that they appeared to not hear it (n = 7 children, during one hint each). The experimenter's goal was always to assist the child in a standardized way without ever taking control of the process or making the child feel as though they were being instructed. If a child asked a question during the exploration period, they were told "*I want to see if you can figure it out without asking questions*". While it is possible that children interpreted this statement as signaling that succeeding would indicate that they had done so "on their own", we consider this unlikely, as the experimenter's hints—which were given when the child was failing to progress to the next step—could equally be interpreted as a sign that the child was *failing* to figure it out "on their own." Moreover, only a small subset of children asked the experimenter for assistance (n = 23 of the 64 for which video recordings were available), so most children did not hear this statement. If children seemed unengaged, they were asked to "*keep trying for a while,*" as many as three times. If a child expressed a desire to quit, either directly or by returning to listless play three times, the experimenter said "*I'd really like you to see if you can figure it out on your own, but if you want, you can quit and I can just show you. Do you want to quit?*". They then were free to quit if they wished. Children who quit (n = 4) were given direct pedagogical instruction on how to use the machine.

Success criterion. Children were considered to have successfully learned to use the machine if they were able properly place the crayon and initials and, with the power on, trace into the crayon using the letter stencils they had placed in the holder.

Dependent Measures

Children were shown two figures with thought bubbles extending from their heads. One figure represented *them* (sex-matched), learning by "doing and thinking"; the other represented an expert (e.g., the experimenter) who could have helped them learn. Children responded to questions about whether they had learned on their own or with help by choosing between the two figures. To familiarize children with using the thought bubble cartoons to indicate whether they had learned "*by themselves, without watching anyone else or having* *them show or tell you,"* or *"with help from someone else,"* we first asked children to indicate how they had learned how to (a) tie their shoes and (b) knock down unsteady block towers. Since young children find shoelaces challenging and typically learn through repeated demonstrations, while knocking over a block tower is intuitively clear without instruction, these questions additionally allowed us to assess children's tendency to make indiscriminate overoptimistic claims about their learning abilities.

After the familiarization questions, children were reminded of the progression of the learning experience they had just had. Children were shown a picture of the machine they had been given, but then told "I could have given you the machine looking like this", and shown a picture of machine in its "just out of the box" state. They were asked to find two differences (the crayon and initials in position, as though left by the previous user) to ensure that they saw the difference between the machine they had been given and the unscaffolded machine. If they could not point out the differences, the differences were pointed out. This ensured that the two possible learning contexts (scaffolded vs. unscaffolded) were made as explicit as possible without telling the children that they'd been helped. Next, children were reminded of all the steps necessary to use the machine, and then reminded (using the thought bubbles) that *they* had not known how to use the machine at first, but the experimenter *had* known.

Next, children were asked whether they had learned to *use the machine* and learned the *name* of the machine *"by yourself, without watching anyone else or having them show or tell you"* or *"with help from someone else."* Lastly, children were asked two counterfactual questions, to which they responded by choosing between two cartoon figures working on the machine: one looking confused, one looking happy. First, they were asked whether or not they would have learned the *name of the person* who had used the machine before them (which they had been told during the introduction). Finally, they were shown a video of the unscaffolded introduction, and asked whether they would have learned to *use the machine* or not, had experimenter done everything *"just like in the video"* and then left them on their own *"for just a little bit, to try to learn to how to use the machine."*

Results and Discussion

The key comparison was between scaffolded children's judgments that they would have learned to use the machine without scaffolding and the actual success rates of the unscaffolded children in their age group. Though no unscaffolded children in either age group had succeeded in learning to use the machine, scaffolding was highly effective, as 39 of 40 (97.5%) children in the older group succeeded, and 35 of 40 (87.5%) in the younger group succeeded. However, when we asked scaffolded children whether they would have learned *without* scaffolding, children were strikingly unaware of their limitations: only 25% of the younger group and 35% of the older group realized that they would not have learned to use the machine without help (Figure 1). In support of our prediction, these counterfactual claims of success from the scaffolded children differed significantly from the actual success rates of the unscaffolded children for the sample as a whole, $\chi^2(1, N = 123) = 52.472$, $p < .001$, as well as for both age groups independently, (Older: $\chi^2(1, N = 60) = 20.37$, $p < .001$; Younger: $\chi^2(1, N = 63) = 29.994$, $p < .001$). Surprisingly, older children were not significantly better than younger children at recognizing their reliance on others to learn to use the machine, $\chi^2(1, N = 80) = 0.53571$, $p = ns$). While we expected older children to overestimate individual learning capacities compared to the unscaffolded baseline, past work has suggested that younger children are much more prone to overestimate their own knowledge than older children. Here both groups of children were approximately equally likely to neglect scaffolding in judging their ability to learn without access to a knowledgeable other. Note that children claimed that scaffolding was unnecessary despite being shown a video of the unscaffolded introduction, suggesting that they were not simply assuming that seeing the "previous user's" materials left in place would have allowed them to reverse engineer the use of the machine even without the experimenter's verbal hints.

Also supporting our predictions, children's overestimation of their ability to learn without assistance was not a failure of (a) source-monitoring, (b) counterfactual thinking, or (c) general egocentrism, nor did they fail to recognize that some kinds of information could *not* be learned without assistance (Figures 1 and 2). We report binomial comparisons to chance; the age groups did not differ on any measure (chi-squareds all *ns*). First, both younger and older children recognized that they learned to *use* the machine with help from the experimenter ($M_{old} = 87.5\%$, $M_{young} = 82.5\%$, binomial ps $< .001$), and that they learned the *name* of the machine with help from the experimenter ($M_{old} = 87.5\%$,

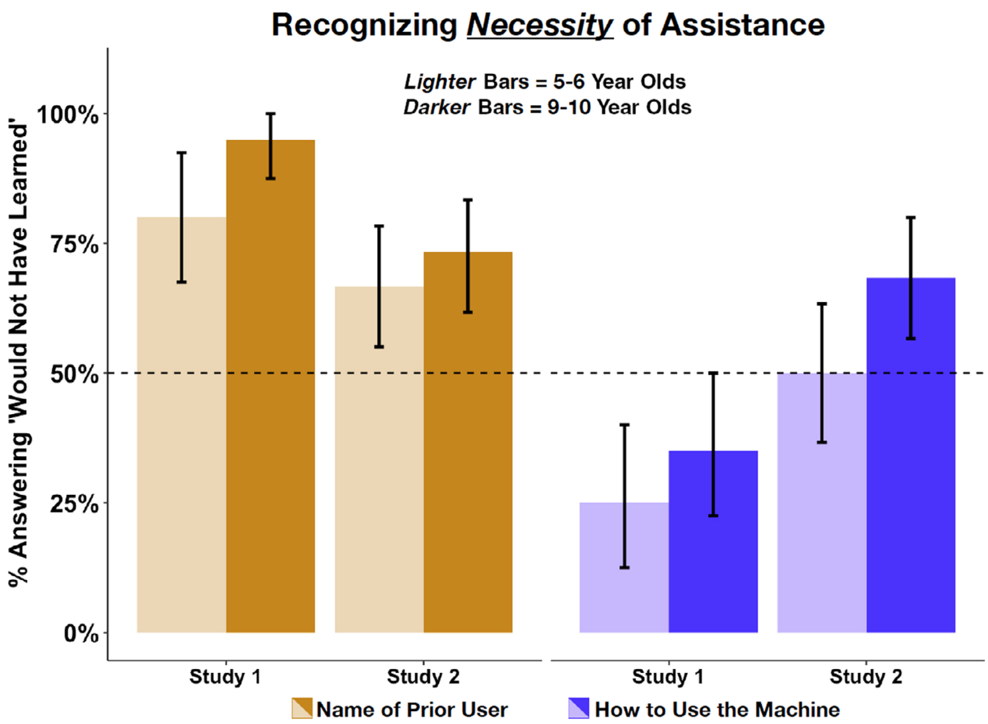

Figure 1. Results for the two "would you have learned without help" questions in Study 1 and Study 2. *Lighter* bars represent the younger age group (5–6), *darker* bars represent the older group (9–10). *Brown* bars represent the percentage of children recognizing that they would not have learned the name of the person who had used the machine before them if the experimenter had not told them. *Blue* bars represent the percentage of children recognizing that they would not have learned to use the machine without scaffolding. Error bars represent 95% CI. The dashed line represents chance responding.

M_{young} = 77.5%, binomial $ps < .001$), suggesting that their overestimation was not simply a failure of source monitoring. Second, both younger and older children recognized that they *could not* have learned the name of the person who had used the machine before them if the experimenter had not told them (M_{old} = 95.0%, M_{young} = 80.0%, binomial $ps < .001$), suggesting that children understood the distinction between direct and indirect knowledge, and were not simply unable to think counterfactually. Finally, all children reported that they had learned to tie their shoes with help (M_{old} = 95.0%, M_{young} = 87.5%, binomial $ps < .001$), but had learned how to knock down unsteady block towers by themselves (M_{old} = 87.5%, M_{young} = 87.5%, binomial $ps < .001$). These results provide additional evidence that children's failure to recognize their reliance on scaffolding was specific to the scaffolded artifact, rather than a result of general overoptimism or egocentrism. Were children simply overoptimistic or egocentric, they would have also claimed to have learned to tie their shoes without help.

Study 2: Observing a Third Party Scaffolded

If children's experience of their own reasoning processes during trial-and-error exploration of an artifact masks the importance of expert assistance for learning about that artifact, then an observer, who has no access to the learner's reasoning process, should be better able to recognize the necessity of expert assistance. This prediction is reminiscent of the person-situation distinction of attribution theory (e.g., Ross, 1977). However, we are not predicting inferences about the learner's competence as a character trait. While we do predict that observers will be more likely to recognize that the learner needed scaffolding to learn to use the artifact, we expect observers to respond similarly to first-person participants for all other measures. For example, we predict that observers will still recognize that no assistance would be needed to learn how to knock down a block tower. If classic actor-observer differences explained our findings, observers would be more likely to claim that learners required assistance across all measures, from tying shoes to using the machine, because observers would simply

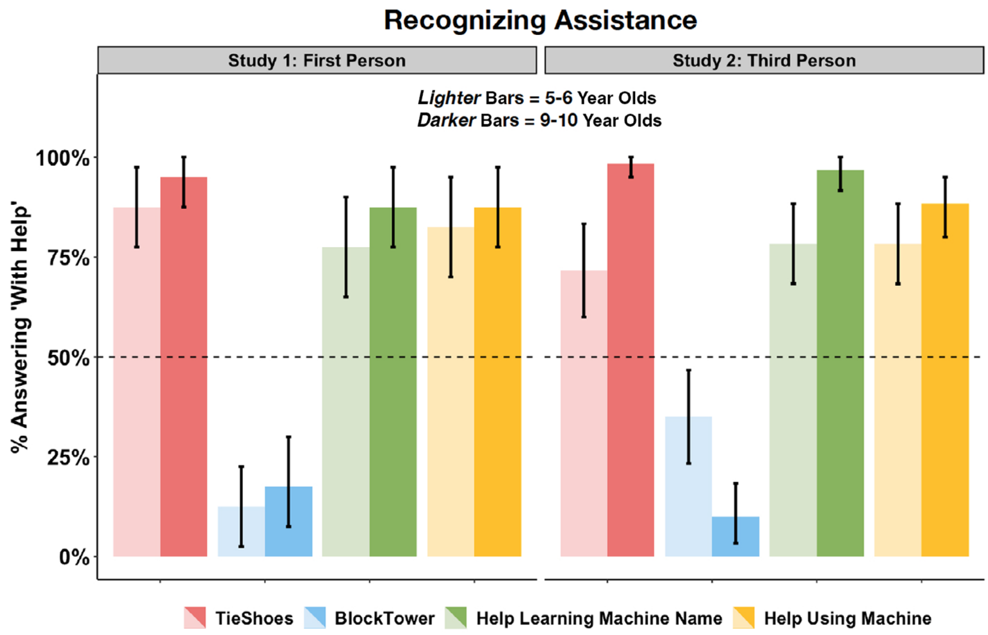

Figure 2. Results for the four "did you learn on your own, or with help" questions in Study 1 and Study 2. *Lighter* bars represent the younger age group (5–6), *darker* bars represent the older group (9–10). "*Learned from other(s)*" was coded as correct for *TieShoes*, *Machine-Name*, and *HelpUsingMachine*, whereas "*Learned without help*" was coded as correct for *BlockTower*. Error bars represent 95% CI. The dashed line represents chance responding.

consider them more dependent on outside assistance. Children in Study 2 watched a video of a 3rd party learning to use the pantograph through scaffolding. A sample size of 60 per age group was chosen to detect a moderate-to-large effect in a chi-squared test, as determined by a power analysis using the pwr package in R (Champely et al., 2018). The design and hypotheses were preregistered, and all data and materials are available at the Open Science Framework repository.

Method

Participants

Sixty-three children ages 5–6 (M_{age} = 5.49) and sixty-four children ages 9–10 (M_{age} = 9.52) were recruited in fall 2018 through spring of 2019 via our online platform, which allows families from around the United States to participate via a high-fidelity videochat with a researcher (Sheskin & Keil, 2018). Seven children were excluded from analysis; four due to technical difficulties with the internet connection (two 5- to 6-year-olds, two 9- to 10-year-olds), two for recognizing the crayon carver and knowing either the function or name (one 6-year old, one 10-year old), and one for parental interference (9-year old). The final sample consisted of 60 younger and 60 older children (49% girls). Families have the option of submitting race and location data when signing up for studies on our platform; the participants in this study reporting their ZIP code represented 100 ZIP codes in 39 U.S. states. The average yearly income for these ZIP-codes is approximately $46,700. 68.5% of our sample identified as white, 12.6% declined to respond, and 18.9% identified as Hispanic, Asian, or African-American.

Materials and Procedures

The procedure was similar to Study 1, but from a third-person perspective. The children were told they would watch a child their age learning to use the machine. The camera angle in the video was zoomed in to show the machine, and so only the hands of the confederate and those of the experimenter were visible. This set up represents a difference in context from Study 1; children in Study 2 were at home next to their parents, and separated from the experimenter, whereas children in Study 1 sat next to the experimenter in a museum with their parents behind them. However, children in Study 1 were typically engrossed by the machine, rarely looking at the experimenter even when hints were provided, making it unlikely that children's responses in Study 1 were influenced by facial information or body language, to which children in Study 2 had no access. The confederate in the video received four hints during the exploration phase: placing the caps on the crayon, placing the crayon in the vice, placing the initials in the peg-board, and turning on the power. These were the four hints (of the eight kinds possible) most commonly given to the scaffolded participants in Study 1. We then asked participants the same set of questions as in Study 1, but from a third-person perspective.

Results and Discussion

In support of our prediction that children who took a third-person perspective would better recognize that the scaffolding was necessary, the children in Study 2 were significantly more likely than the children in Study 1 to say that the scaffolded learner would not have learned to use the machine without help (Figures 1 and 2). The third-person advantage was observed in both preregistered analyses: accuracy was higher both collapsing across age group ($M_{\text{Study 1}}$ = 30%, $M_{\text{Study 2}}$ = 59.2% $\chi^2(1, N = 200) = 15.226$, $p < .001$), and for each age group independently (Younger: $M_{\text{Study 1}}$ = 25.0%, $M_{\text{Study 2}}$ = 50.0% $\chi^2(1, N = 100) = 5.2517$, $p = .022$, Older: $M_{\text{Study 1}}$ = 35%, $M_{\text{Study 2}}$ = 68.3% $\chi^2(1, N = 100) = 9.4697$, $p = .002$. Older children in Study 2 were also significantly more likely than chance to say that the learner would have failed without scaffolding; younger children did not differ from chance (binomial, M_{old} = 68.3% $p = .003$, M_{young} = 50.0% $p = ns$). However, children in both age groups in Study 2 continued to significantly underestimate the necessity of scaffolding when compared with actual success rates in the unscaffolded condition (All: $\chi^2(1, N = 163) = 23.201$, $p < .001$, Older: $\chi^2(1, N = 80) = 6.6494$, $p < .01$; Younger: $\chi^2(1, N = 83) = 15.908$, $p < .001$).

As in Study 1, the pattern of results for the secondary preregistered measures speaks against simple failures of source monitoring, counterfactual thinking, general egocentrism, and a failure to distinguish between directly and indirectly acquired knowledge more broadly (Figures 1 and 2), in accordance with our predictions. Even the youngest children reported that the learner was helped in learning to *use* the machine (M_{old} = 87.9%, M_{young} = 77.9%, binomial ps < .001) and in learning the *name* of the machine (M_{old} = 96.7%, M_{young} = 78.3%, binomial ps < .001). Likewise, both age groups also believed that the learner could *not* have learned the name of the previous user if the experimenter had not told them (M_{old} = 95.0%, M_{young} = 80.0%, binomial ps < .001). Finally, both age groups reported that the learner had learned to tie their shoes with help (M_{old} = 98.3%, M_{young} = 71.7%, binomial ps < .001), but had learned how to knock down unsteady block towers by themselves (M_{old} = 90.0%, M_{young} = 65.0%, binomial $p_{\text{old}} < .001$, $p_{\text{young}} < .018$).

Importantly, if children's increased recognition of scaffolding when taking a third-person perspective was caused by general egocentric biases or a tendency to attribute others' failures to general incompetence, we would see an increased tendency to claim that the learner was helped in Study 2 versus Study 1 across all measures. No such tendency was observed. Aside from the question of the learner's ability to figure out the machine without help, older children's responses differed between Study 1 and Study 2 only for the counterfactual control question, where they were *more* likely in Study 2 to say that the learner would have figured out the name of the previous user without help (χ^2(1, N = 100) = 6.2359, $p = .013$). Younger children's responses differed significantly only for Block-Tower; here, the difference was indeed a tendency to claim that the learner needed help ($\chi^2(1, N = 100) = 6.2359$, $p = .013$). However, no other measure differed significantly from Study 1, and contrary to a general bias account, there was *less* of a tendency for younger children to claim that the learner needed help in Study 2 than in Study 1.

General Discussion

We asked whether children learning to use an artifact through a combination of self-directed exploration and subtle expert scaffolding would overestimate their ability to learn on their own. The stark contrast between the 0% unscaffolded success rate and the 70% of children who claimed that they would have succeeded without scaffolding suggests that children overestimate the extent to which their own exploration is sufficient to learn to use artifacts. However, this illusion of self-sufficiency was specific to the scaffolded artifact and the scaffolded child. Scaffolded children did not believe that they could have figured out the name of the previous user without assistance, nor did they fail to recognize that the experimenter had helped them learn to use the machine and had told them the name of the machine. Children who simply observed another learner being scaffolded but did not explore the artifact themselves did not experience the illusion. Rather, the only qualitative difference between scaffolded children's judgments of how they had learned in Study 1 and the judgments of observers in Study 2 was that children who observed a learner being scaffolded were more likely to report that the scaffolding was necessary.

We have argued that children's ability to reason fruitfully about artifacts in scaffolded contexts leads them to overestimate the power of self-directed exploration. Importantly, self-directed exploration must be able to reveal *something* for scaffolding to even be possible in the first place. Indeed, if a learner is unable to learn anything at all through self-directed exploration, it would be disconcerting or frustrating for a teacher to attempt to scaffold them instead of simply instructing them. For example, though the machine name was descriptive ("crayon carver") and we told the children the name of the previous user while pointing out the stencil-initials that they had left behind, one cannot "scaffold" object labels or historical facts. Such information must be directly taught. Conversely, the reuse of common features makes scaffolding a naturally efficient pedagogical approach for artifacts. Consider a learner who is familiar with buttons being shown a music box with a few conspicuous buttons; the learner can anticipate on sight that some manner of pressing the buttons will probably cause music to play, before the teacher says anything. In that case, a teacher that chooses to explicitly instruct the learner instead of scaffold independent exploration may provoke unintended pragmatic inferences.

However, while we believe that children's experience of their own reasoning about artifacts masks the importance of expert scaffolding, we have not compared learning to use artifacts through scaffolding with learning through more direct forms of pedagogy. Initially, we had intended to make this more general claim about scaffolding: as with artifacts, most knowledge combines both directly accessible aspects and those that are only accessible with assistance, but because scaffolding allows learners to focus on what they can in fact learn directly, scaffolding *per se* may lead us to overestimate our individual learning capacities in ways that other forms of pedagogy do not. For example, if direct pedagogy forces learners to shift their focus from their own reasoning about the artifact to attempting to internalize the information being presented to them, learners may infer that the information is being taught directly *because* it is inaccessible through exploration. However, coronavirus disease 19 forced us to postpone the additional experiments; thus, at present, the effect of direct instruction on the illusion of self-sufficiency for artifacts remains an open question.

Our work suggests practical as well as theoretical questions. Recent work has suggested that children's inferences in pedagogical contexts start from an assumption that instruction is maximally informative. For example, if a teacher's instruction provides no evidence that an artifact has additional functions, preschoolers interpret that *absence of evidence* as *evidence of the absence* of such functions, and explore less afterward, discovering fewer untaught functions as a result (Bonawitz et al., 2011; Shneidman, Gweon, Schulz, & Woodward, 2016). However, when learners are led to believe that a particular teacher usually does *not* teach every function, children explore more afterward, and may assume that the functions that *are* taught are significantly more important than if they know that the teacher usually *does* teach every function (Bass, Shafto, & Bonawitz, 2018; Gweon, Pelton, Konopka, & Schulz, 2014). Thus, scaffolding may be an efficient way to transmit otherwise inaccessible skills without discouraging exploration (Yu et al., 2018). Skills that involve coordinating a complex series of actions and situation-specific inferences may be impossible to master in one shot, but learners who attribute their original success to themselves may be more likely to persist alone even in the absence of guidance later; in this respect, overoptimism may be adaptive (Lockhart, Goddu, & Keil, 2017). Indeed, some evidence suggests that children who mistakenly attribute their partner's contributions to themselves in a joint task actually perform better at retest (Ratner et al., 2002; Sommerville & Hammond, 2007). However, in other cases, children who participate in joint-action tasks with a partner fail at retest because they only reproduce their own actions, whereas children who merely observe joint-action or complete the task alone are more successful (Milward & Sebanz, 2018). Thus, future work must still determine the conditions under which illusions of self-sufficiency have positive or negative effects on learning itself.

Future work could also consider whether this illusion is found in other cultural contexts. As we noted earlier, scaffolding is common across cultures, particularly in causal learning contexts such as the use of artifacts (see Legare, 2017, for review). However, caregivers' approaches to scaffolding differ across cultures, and even within cultures. For example, while middle-class European-American mothers frequently correct their individual children *verbally*, in Indigenous communities in Mexico, children are expected to learn more by *observing*, even when the caregiver is not focused on them individually; and in other cultures, caregivers are more likely to *physically* intervene (Little et al., 2016; Silva et al., 2010). The WEIRD children (Henrich, Heine, & Norenzayan, 2010; Nielsen, Haun, Kartner, & Legare, 2017) in our sample could have interpreted the experimenter's relative restraint in verbally correcting them as a positive sign of their individual competence. Children who are primarily taught through observation may be more likely to conclude that they learned because of the introductory scaffolding; in contrast, children accustomed to caregivers physically guiding them may have interpreted the experimenter's lack of physical intervention as indicating that they were learning without assistance. On our account, children across cultures will be more likely to experience an illusion of self-sufficiency for artifacts than for more clear-cut cases of direct and indirect knowledge such as historical facts and objects labels; but, if the illusion is also exacerbated by the pedagogical approach, cultural differences may emerge.

Alternative accounts do not explain the pattern of results we observed in these studies. Conceivably, children in Study 1 might have failed to discount their newfound knowledge in assessing their independent learning ability because of hindsight bias; however, hindsight bias cannot explain why observers in Study 2, who had access to the same information as the learners in Study 1 (with the exception of the learner's own thinking), better recognized the necessity of scaffolding. Hindsight bias instead predicts that knowledgeable observers would expect the artifact to be *more* transparent to a naive learner (Bernstein, Atance, Loftus, & Meltzoff, 2004; Birch & Bernstein, 2007). Nor were children's judgments a simple failure of source monitoring. Past work with preschoolers has revealed a strong tendency to claim prior knowledge of just-learned facts and, to a lesser extent, behaviors, but by age six egocentric errors for novel facts are rare (Drummey & Newcombe, 2002; Gopnik & Graf, 1988; Tang & Bartsch, 2012; Taylor, Esbensen, & Bennett, 1994). In our studies, children in both age groups accurately reported learning the artifact's name from the experimenter, and learning to tie their shoes with help from someone else. Children's answers to those questions also suggest that the stark contrast between the counterfactual question in Study 1 and Study 2 was not merely due to egocentric assessments relative to others (Stipek & Mac Iver, 1989). While children were approximately twice as accurate in the third person for the counterfactual success measure, they showed similarly high degrees of accuracy across self and other for all questions (Figure 2). Similarly, if egocentrism influenced children's judgments about unscaffolded learning capacities, one might expect children who claimed to have learned to tie their shoes on their own to be more likely to claim that scaffolding was unnecessary. However, there was no such relationship for either age group individually or taken together, in either experiment on its own, or in the data as a whole. Thus, children's overconfidence is specific to the use of the scaffolded artifact, not a general egocentric bias.

Our method was limited in that our results were based on children's reports in response to direct questions from the experimenter, and so are subject to be influenced by the answer children believe is expected. For example, children's judgments of whether they would have succeeded without help were metacognitive judgments about a counterfactual context, and could only be elicited by direct questioning. Counterfactual reasoning can be challenging for young children, particularly because it frequently involves judgments about what parts of the past the questioner is asking them to change or keep the same—for example, if the experimenter had asked "would you have learned to use the machine if I hadn't helped you?", children would have needed to decide what constituted "help," whether the experimenter intended to exclude all other people who could have helped them, and so on. Failure to appropriately interpret the questioners' intent may lead to failures of counterfactual judgment even in later childhood (Rafetseder & Perner, 2018); yet, when the question is made clear, even 5-year-olds perform at ceiling (Nyhout & Ganea, 2019; Nyhout, Henke, & Ganea, 2017; Kominsky et al., 2019). We attempted to minimize the need to interpret the experimenter's question (e.g., what counts as "help") by simply showing children a video of what the unscaffolded introduction would look like before asking them whether they would have learned without the experimenter present. Despite this, children claimed that they would have learned to use the machine. However, a counterfactual question presented as a control caused children no difficulty in either study: nearly all responded that they would not have learned the name of child who had used the machine previously if the experimenter had not told them. Moreover, a general failure of counterfactual reasoning would predict identical patterns between observers and learners.

Our results may also suggest future directions for work on fluency effects (Alter & Oppenheimer, 2009; Sidarus, Vuorre, Metcalfe, & Haggard, 2017). We have argued that artifacts' reuse of common features, which allows learners to discover some aspects of an artifact's use-schematic independently, contributes to artifacts' illusory transparency in scaffolded learning contexts; in contrast, the inaccessible nature of indirect knowledge, such as an object label, makes clear the limits of independent learning. To use the terminology of fluency, exploring artifacts with familiar features presumably enables more fluent inferences than either exploring totally novel artifacts, or attempting to guess an object's label. Thus, our argument suggests avenues for research on how artifacts' design may influence learner's *prospective* judgments of how much help they would need. However, a fluency account is underspecified with regard to the *retrospective* judgments elicited here: having learned the use of the artifact through scaffolding and the name of the prior user through direct instruction, retrieving that knowledge is (if anything) *more* fluent for the *name* than the more complex use-schema. Yet, children recognize that the name of the prior user would be inaccessible for an independent learner, while claiming that the *less* fluent use-schema *would* be accessible, suggesting inductive biases other than mere fluency were at work. Future work could ask if there might be a joint role of fluency and pedagogical approach in illusions about artifacts. For example, scaffolding may exacerbate the illusion in part because it allows for a more continuous "flow" in the learning process than direct instruction. Breaking that flow may make the learning process less fluent. If instead of asking leading questions contingently on a child's performance, the scaffolder suggested (still contingently on the child's performance) that the child look at a piece of paper with the exact same leading question, the comparative disfluency of pausing to read a written hint may make it easier to distinguish between solutions they "would have tried" on their own and solutions provided by others (cf. Fisher, Goddu, & Keil, 2015).

The strength of the illusion even in older children may be symptomatic of a broader tendency to overestimate the transparency of artifacts, even as adults. Adults' and children's ratings of how well they understand everyday artifacts drop sharply when asked to give a step-by-step, mechanistic explanation of how the artifact works, reflecting the gap between the artifact's mechanical complexity and the skeletal representation of it needed in everyday life (Lawson, 2006; Mills & Keil, 2004; Rozenblit & Keil, 2002). Indeed, in everyday life, a detailed understanding of all the causal structures in our natural and engineered environments is rarely necessary; nevertheless, the skeletal theories we do maintain include some information about artifacts' complexity. For adults, an artifact's complexity seems to be most strongly related to how much help they believe they would need to *fix* it, whereas for 9- and 10-year old children, complexity is most strongly related to how much help they believe they would need to *use* it (Kominsky et al., 2017). It may be that people's default representation of an artifact is simply a schematic of how to use it, and it is this schematic that they initially retrieve, while the more detailed representation of the artifact's mechanical complexities is reconstructed only if needed (Johnson, Murphy, & Messer, 2016). Learning to use an artifact *without* assistance is in many cases tantamount to attempting to create such a use-schematic by analyzing the mechanical complexities. Pedagogical support allows us to bypass the mechanical complexities, but may also hide them. Future work might contrast the trade-offs of different pedagogical approaches—such as free discovery, guided exploration, and direction instruction—between efficiency of learning and depth of understanding.

Access to experts and the ability to make use of others' expertise allows us to learn far more than we ever could on our own. As with novel artifacts, solving novel problems in other domains often involves placing the right constraints on enormous hypothesis spaces. Our studies suggest that children underestimate the extent to which the social environment shapes the problem-solving strategies they employ. Understanding when and why children fail to recognize the effects of implicit scaffolding may help us better understand how to solve the more complex problems we face on a daily basis.

References

Ahl, R. E., Amir, D., & Keil, F. C. (2020). The world within: Children are sensitive to internal complexity cues. *Journal of Experimental Child Psychology*, *200*, 104932. https://doi.org/10.1016/j.jecp.2020.104932

Alter, A. L., & Oppenheimer, D. M. (2009). Uniting the tribes of fluency to form a metacognitive nation. *Personality and Social Psychology Review*, *13*, 219–235. https://doi.org/10.1177/1088868309341564

Barber, S. J., Franklin, N., Naka, M., & Yoshimura, H. (2010). Higher social intelligence can impair source memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *36*(2), 545–551. https://doi.org/10.1037/a0018406

Bass, I., Shafto, P., & Bonawitz, E. (2018) *That'll teach 'em: How expectations about teaching styles may constrain inferences* (Open Science Framework). https://doi.org/10.31219/osf.io/cxkn9
Bernstein, D. M., Atance, C., Loftus, G. R., & Meltzoff, A. (2004). We Saw It All Along: Visual Hindsight Bias in Children and Adults. *Psychological Science*, *15*, 264–267. https://doi.org/10.1111/j.0963-7214.2004.00663.x
Birch, S., & Bernstein, D. (2007). what can children tell us about hindsight bias: A fundamental constraint on perspective–taking? *Social Cognition*, *25*, 98–113. https://doi.org/10.1521/soco.2007.25.1.98
Boblett, N. (2012). Scaffolding: Defining the metaphor. *Working Papers in TESOL & Applied Linguistics*, *12*(2), 1–16.
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. https://doi.org/10.1016/j.cognition.2010.10.001
Bonawitz, E., van Schijndel, T., Friel, D., & Schulz, L. (2012). Children balance theories and evidence in exploration, explanation, and learning. *Cognitive Psychology*, *64*, 215–234. https://doi.org/10.1016/j.cogpsych.2011.12.002
Bridgers, S., Jara-Ettinger, J., & Gweon, H. (2020). Young children consider the expected utility of others' learning to decide what to teach. *Nature Human Behaviour*, *4*, 144–152. https://doi.org/10.1038/s41562-019-0748-6
Champely, S. (2018). *pwr: Basic functions for power analysis*. R package version 1.2-2.
Champely, S., Ekstrom, C., Dalgaard, P., Gill, J., Weibelzahl, S., Anandkumar, A., . . . De Rosario, H. (2018). *Basic functions for power analysis*. R Package Version. Retrieved from https://cran.r-project.org/web/packages/pwr/pwr.pdf
Csibra, G., & Gergely, G. (2006). Social learning and social cognition: The case for pedagogy. *Processes of Change in Brain and Cognitive Development. Attention and Performance XXI*, *21*, 249–274.
Csibra, G., & Gergely, G. (2011). Natural pedagogy as evolutionary adaptation. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*, 1149–1157.
Drummey, A., & Newcombe, N. (2002). Developmental changes in source memory. *Developmental Science*, *5*, 502–513. https://doi.org/10.1111/1467-7687.00243
Fisher, M., Goddu, M. K., & Keil, F. C. (2015). Searching for explanations: How the Internet inflates estimates of internal knowledge. *Journal of Experimental Psychology: General*, *144*, 674–687. https://doi.org/10.1037/xge0000070
Foley, M. A., Foley, H. J., Durley, J. R., & Maitner, A. T. (2006). Anticipating partners' responses: Examining item and source memory following interactive exchanges. *Memory & Cognition*, *34*, 1539–1547. https://doi.org/10.3758/BF03195917
Foley, M. A., Passalacqua, C., & Ratner, H. H. (1993). Appropriating the actions of another: Implications for children's memory and learning. *Cognitive Development*, *8*, 373–401. https://doi.org/10.1016/S0885-2014(05)80001-2
Foley, M. A., Ratner, H. H., & House, A. T. (2002). Anticipation and source-monitoring errors: Children's memory for collaborative activities. *Journal of Cognition and Development*, *3*, 385–414. https://doi.org/10.1080/15248372.2002.9669675
Gergely, G., & Csibra, G. (2006). Sylvia's recipe: The role of imitation and pedagogy in the transmission of cultural knowledge. In N. J. Enfield & S. C. Levenson (Eds.), *Roots of human sociality: culture, cognition, and human interaction* (pp. 229–255). Oxford, UK: Berg.
Gopnik, A. (2012). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. *Science*, *337*, 1623–1627. https://doi.org/10.1126/science.1223416
Gopnik, A., & Graf, P. (1988). Knowing how you know: Young children's ability to identify and remember the sources of their beliefs. *Child Development*, *59*, 1366. https://doi.org/10.2307/1130499
Gweon, H., Pelton, H., Konopka, J. A., & Schulz, L. E. (2014). Sins of omission: Children selectively explore when teachers are under-informative. *Cognition*, *132*(3), 335–341. https://doi.org/10.1016/j.cognition.2014.04.013
Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and Brain Sciences*, *33*(2–3), 61–83. https://doi.org/10.1017/S0140525X0999152X
Johnson, D. R., Murphy, M. P., & Messer, R. M. (2016). Reflecting on explanatory ability: A mechanism for detecting gaps in causal knowledge. *Journal of Experimental Psychology: General*, *145*, 573–588. https://doi.org/10.1037/xge0000161
Johnson, M. K., Hashtroudi, S., & Lindsay, S. (1993). Source monitoring. *Psychological Bulletin*, *114*(1), 3–28.
Kärtner, J., Keller, H., Lamm, B., Abels, M., Yovsi, R. D., Chaudhary, N., & Su, Y. (2008). Similarities and differences in contingency experiences of 3-month-olds across sociocultural contexts. *Infant Behavior and Development*, *31*, 488–500. https://doi.org/10.1016/j.infbeh.2008.01.001
Kloo, D., Rohwer, M., & Perner, J. (2017). Direct and indirect admission of ignorance by children. *Journal of Experimental Child Psychology*, *159*, 279–295. https://doi.org/10.1016/j.jecp.2017.02.014
Kominsky, J. F., Gerstenberg, T., Pelz, M., Singmann, H., Sheskin, M., & Keil, F. C. (2019). *The trajectory of counterfactual simulation in development*. Conference proceeding and poster presentation, Cognitive Science Society annual meeting, July 24–27, 2019.
Kominsky, J., Zamm, A., & Keil, F. (2017). Knowing when help is needed: A developing sense of causal complexity. *Cognitive Science*, *42*, 491–523. https://doi.org/10.1111/cogs.12509
Landau, J. D., & Marsh, R. L. (1997). Monitoring source in an unconscious plagiarism paradigm. *Psychonomic*

Bulletin & Review, *4*, 265–270. https://doi.org/10.3758/BF03209404
Lawson, R. (2006). The science of cycology: Failures to understand how everyday objects work. *Memory & Cognition*, *34*, 1667–1675. https://doi.org/10.3758/BF03195929
Legare, C. (2017). Cumulative cultural learning: Development and diversity. *Proceedings of the National Academy of Sciences of the United States of America*, *114*, 7877–7883. https://doi.org/10.1073/pnas.1620743114
Little, E., Carver, L., & Legare, C. (2016). Cultural variation in triadic infant-caregiver object exploration. *Child Development*, *87*, 1130–1145. https://doi.org/10.1111/cdev.12513
Lockhart, K., Goddu, M., & Keil, F. (2017). Overoptimism about future knowledge: Early arrogance? *The Journal of Positive Psychology*, *12*(1), 36–46. https://doi.org/10.1080/17439760.2016.1167939
Lockhart, K., Goddu, M., Smith, E., & Keil, F. (2016). What could you really learn on your own?: Understanding the epistemic limitations of knowledge acquisition. *Child Development*, *87*, 477–493. https://doi.org/10.1111/cdev.12469
Lyons, D. (2008). The rational continuum of human imitation. In J. A. Pineda (Ed.), *Mirror Neuron Systems* (pp. 77–103). Totowa, NJ: Humana Press. https://doi.org/10.1007/978-1-59745-479-7_4
Lyons, D., Damrosch, D., Lin, J., Macris, D., & Keil, F. (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. https://doi.org/10.1098/rstb.2010.0335
Magid, R. W., Sheskin, M., & Schulz, L. E. (2015). Imagination and the generation of new ideas. *Cognitive Development*, *34*, 99–110. https://doi.org/10.1016/j.cogdev.2014.12.008
Mermelshtine, R. (2017). Parent–child learning interactions: A review of the literature on scaffolding. *British Journal of Educational Psychology*, *87*, 241–254. https://doi.org/10.1111/bjep.12147
Mills, C., & Keil, F. (2004). Knowing the limits of one's understanding: The development of an awareness of an illusion of explanatory depth. *Journal of Experimental Child Psychology*, *87*(1), 1–32. https://doi.org/10.1016/j.jecp.2003.09.003
Milward, S., & Sebanz, N. (2018). Imitation of coordinated actions: How do children perceive relations between different parts? *PLoS One*, *13*(1), e0189717. https://doi.org/10.1371/journal.pone.0189717
Nielsen, M., Haun, D., Kärtner, J., & Legare, C. H. (2017). The persistent sampling bias in developmental psychology: A call to action. *Journal of Experimental Child Psychology*, *162*, 31–38. https://doi.org/10.1016/j.jecp.2017.04.017
Nyhout, A., & Ganea, P. A. (2019). Mature counterfactual reasoning in 4- and 5-year-olds. *Cognition*, *183*, 57–66. https://doi.org/10.1016/j.cognition.2018.10.027
Nyhout, A., Henke, L., & Ganea, P. A. (2017). Children's counterfactual reasoning about causally overdetermined events. *Child Development*. https://doi.org/10.1111/cdev.12913
Rafetseder, E., & Perner, J. (2018). Belief and counterfactuality: A teleological theory of belief attribution. *Zeitschrift Für Psychologie*, *226*, 110–121. https://doi.org/10.1027/2151-2604/a000327
Ratner, H. H., Foley, M. A., & Gimpert, N. (2002). The role of collaborative planning in children's source-monitoring errors and learning. *Journal of Experimental Child Psychology*, *81*(1), 44–73. https://doi.org/10.1006/jecp.2001.2643
Reindl, E., Bandini, E., & Tennie, C. (2018) The zone of latent solutions and its relation to the classics: Vygotsky and Köhler. In L. Di Paolo, F. Di Vincenzo, & F. De Petrillo (Eds.), *Evolution of primate social cognition* (pp. 231–248). Cham, Switzerland: Springer International. https://doi.org/10.1007/978-3-319-93776-2_15
Reindl, E., Beck, S., Apperly, I., & Tennie, C. (2016). Young children spontaneously invent wild great apes' tool-use behaviours. *Proceedings of the Royal Society B: Biological Sciences*, *283*, 20152402. https://doi.org/10.1098/rspb.2015.2402
Rogoff, B. (1990). *Apprenticeships in thinking: Cognitive development in social context*. Oxford, UK: Oxford University Press.
Rogoff, B. (2014). Learning by observing and pitching in to family and community endeavors: An orientation. *Human Development*, *57*(2–3), 69–81. https://doi.org/10.1159/000356757
Ross, L. (1977). The intuitive psychologist and his shortcomings- Distortions in the attribution process. In *Advances in experimental social psychology* (Vol. *10*, pp. 173–220). Cambridge: Academic Press.
Rozenblit, L., & Keil, F. (2002). The misunderstood limits of folk science: An illusion of explanatory depth. *Cognitive Science*, *26*, 521–562. https://doi.org/10.1207/s15516709cog2605_1
Schulz, L., Gopnik, A., & Glymour, C. (2007). Preschool children learn about causal structure from conditional interventions. *Developmental Science*, *10*, 322–332. https://doi.org/10.1111/j.1467-7687.2007.00587.x
Sheskin, M., & Keil, F. (2018). TheChildLab.com a video chat platform for developmental research. *PsyArXiv*. https://doi.org/10.31234/osf.io/rn7w5
Sidarus, N., Vuorre, M., Metcalfe, J., & Haggard, P. (2017). Investigating the prospective sense of agency: Effects of processing fluency, stimulus ambiguity, and response conflict. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00545
Silva, K., Correa-Chávez, M., & Rogoff, B. (2010). Mexican-Heritage children's attention and learning from interactions directed to others: Mexican-Heritage children's attention. *Child Development*, *81*, 898–912. https://doi.org/10.1111/j.1467-8624.2010.01441.x
Sim, Z., & Xu, F. (2017). Learning higher-order generalizations through free play: Evidence from 2- and 3-

year-old children. *Developmental Psychology*, *53*, 642–651. https://doi.org/10.1037/dev0000278
Shneidman, L., Gweon, H., Schulz, L. E., & Woodward, A. L. (2016). Learning from others and spontaneous exploration: A cross-cultural investigation. *Child Development*, *87*(3), 723–735. https://doi.org/10.1111/cdev.12502
Sobel, D. M., & Letourneau, S. M. (2018). Preschoolers' understanding of how others learn through action and instruction. *Child Development*, *89*, 961–970. https://doi.org/10.1111/cdev.12773
Sobel, D. M., Li, J., & Corriveau, K. H. (2007). "They danced around in my head and I learned them": Children's developing conceptions of learning. *Journal of Cognition and Development*, *8*, 345–369. https://doi.org/10.1080/15248370701446806
Sommerville, J. A., & Hammond, A. J. (2007). Treating another's actions as one's own: Children's memory of and learning from joint activity. *Developmental Psychology*, *43*, 1003–1018. https://doi.org/10.1037/0012-1649.43.4.1003
Stipek, D., & Iver, D. (1989). Developmental change in children's assessment of intellectual competence. *Child Development*, *60*, 521–538. https://doi.org/10.2307/1130719
Tang, C., & Bartsch, K. (2012). Young children's recognition of how and when knowledge was acquired. *Journal of Cognition and Development*, *13*, 372–394. https://doi.org/10.1080/15248372.2011.577759
Taylor, M., Esbensen, B., & Bennett, R. (1994). Children's understanding of knowledge acquisition: The tendency for children to report that they have always known what they have just learned. *Child Development*, *65*, 1581. https://doi.org/10.2307/1131282
Tennie, C., Call, J., & Tomasello, M. (2009). Ratcheting up the ratchet: On the evolution of cumulative culture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*, 2405–2415. https://doi.org/10.1098/rstb.2009.0052
Tomasello, M., Kruger, A. C., & Ratner, H. H. (1993). Cultural learning. *Behavioral and Brain Sciences*, *16*, 495–552. https://doi.org/10.1017/S0140525X00031277
Vredenburgh, C., & Kushnir, T. (2016). Young children's help-seeking as active information gathering. *Cognitive Science*, *40*, 697–722. https://doi.org/10.1111/cogs.12245
Vygotsky, L. (1978). *Mind in society* (M. Cole, S. Scribner, V. John-Steiner, & E. Souberman [Eds.]). Cambridge: Harvard University Press (Original work published 1934).
Walker, C. M., Rett, A., & Bonawitz, E. (2020). Design drives discovery in causal learning. *Psychological Science*, *31*, 129–138. https://doi.org/10.1177/0956797619898134
Was, A. M., & Warneken, F. (2017). Proactive help-seeking: Preschoolers know when they need help, but do not always ask for it. *Cognitive Development*, *43*, 91–105. https://doi.org/10.1016/j.cogdev.2017.02.010
Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, *17*, 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x
Yu, Y., Shafto, P., Bonawitz, E., Yang, S.- C.-H., Golinkoff, R. M., Corriveau, K. H., . . . Xu, F. (2018). The theoretical and methodological opportunities afforded by guided play with young children. *Frontiers in Psychology*, *9*, 11552. https://doi.org/10.3389/fpsyg.2018.011

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Appendix S1. Preliminary Study