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Preschoolers use pedagogical cues to guide radical reorganization of category knowledge

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ABSTRACT

In constructing a conceptual understanding of the world, children must actively evaluate what information is idiosyncratic or superficial, and what represents essential, defining information about kinds and categories. Preschoolers observed identical evidence about a novel object's function (magnetism) produced in subtly different manners: accidentally, intentionally, or demonstrated communicatively and pedagogically. Only when evidence was explicitly demonstrated for their benefit did children reliably go beyond salient perceptual features (color or shape), to infer function to be a defining property on which to base judgments about category membership. Children did not show this pattern when reasoning about a novel perceptual property, suggesting that a pedagogical communicative context may be especially important for children's learning about artifact functions. Observing functional evidence in a pedagogical context helps children construct fundamentally different conceptions of novel categories as defined not by superficial appearances but by deeper, functional properties.

1. Introduction

A foundational developmental process is the acquisition of generic knowledge about kinds and categories that supports the construction of a coherent conceptual understanding of the world (Gelman, 2003; Gelman & Wellman, 1991; Keil, 1989; Markman, 1989). Yet acquisition of such knowledge is often achieved based on limited first-hand information. In many cases children can capitalize on linguistic cues that mark generic knowledge (e.g., Chambers, Graham, & Turner, 2008; Cimpian & Cadena, 2010; Cimpian & Erickson, 2012; Cimpian & Markman, 2009, 2011; Cimpian, Mu, & Erickson, 2012; Gelman, Star, & Flukes, 2002; Hollander, Gelman, & Raman, 2009). But there are many potential contexts, especially involving learning about human-made artifacts, in which children have the opportunity to observe others' actions and must evaluate on non-linguistic bases whether the information those actions produce is generic. Here we describe a series of experiments investigating how preschool children leverage social cues signaling that information is being communicated for their benefit, in order to calibrate what they learn about the world from the actions of knowledgeable adults.

1.1. The inductive problem of generalizing from sparse evidence

The ability to make inferences about the world on the basis of minimal evidence is a critical component of human cognition, allowing us to make predictions, construct explanations, and develop a rich causal understanding of the world. But such inferences must be made on the basis of underdetermined evidence. For example, imagine that a person learns a new fact about an individual animal, say that a bird has rocks in its stomach. Should this person infer that all birds of this kind have rocks in their stomachs?

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That *all* birds have rocks in their stomachs? Or alternatively, that this is something idiosyncratic to only this bird (e.g., it may have swallowed some rocks accidentally), or something particular to a limited set of related birds (e.g., perhaps they hunt worms that live under rocks; Cimpian & Markman, 2009)? One could arguably make any of these generalizations with equal legitimacy based on the given evidence (cf., Goodman, 1965). Calibrating the scope of generalization is especially important for young children who are beginning to construct conceptual frameworks for understanding the world, as they must sift through a flood of new information to do so (Heit & Hahn, 2001; Lopez, Gelman, Gutheil, & Smith, 1992).

One powerful way to address this inductive problem is to reason in terms of kinds and categories—to divide up the world in terms of coherent collections of individuals that share predictable commonalities. This significantly reduces the demands of the inductive problem, allowing us to conceive of unlimited numbers of individuals as equivalent at some deeper level, as being the same kind of thing (Gelman, 2003). This assumption greatly reduces the informational complexity of our environment, and charts an easier path for efficient category-wide generalizations. But even given the ability to reason in terms of kinds and categories, people must evaluate whether a given sample of information is strong evidence for drawing inferences about a broader, unobserved population (see Heit, 2000). Reasoning in terms of kinds and categories may do little to help assess whether a generalization ought to be made in the first place, or how much weight ought to be placed on a particular generalization.

1.2. How children solve the inductive problem

There are arguably a number of ways that children might address this inductive problem, including reasoning about accumulated statistical evidence (Tenenbaum & Griffiths, 2001). In the current research, we focus on a particularly powerful tool that children use to tackle the inductive problem—learning from others (Gelman, 2009).

1.2.1. Generic language

One way that children learn from others is by paying attention to the language others use when they talk about new information, especially by paying attention to cues that information is *generic*—that the speaker is expressing information directly about a kind or category as a whole. We can express much of our knowledge about the world using generic language. Generic utterances (e.g., "birds have rocks in their stomachs") differ from specific utterances (e.g., "this bird has rocks in its stomach") in that they refer not to a particular individual or even a collection of individuals (e.g., "those birds have rocks in their stomachs"), but to the kind as a whole (Carlson & Pelletier, 1995; Gelman, 2003, 2004; Leslie, 2007; Leslie, 2008; Prasada, 2000). Because of this, generic language enables people to efficiently acquire knowledge about a kind even with limited experience with individual members of that kind. Indeed, we cannot directly observe mappings between properties and kinds, as we can never observe all the members of a category. And it may be difficult or impossible to provide direct evidence for such a mapping without generic language (Gelman, 2004).

By age 3 or 4 children are highly sensitive to generic language, and it shapes the way they reason about new information. Generic language can link properties to their relevant categories (Prasada, 2000; Prasada & Dillingham, 2006; Shipley, 1993), leading children to view properties as both more *generalizable* across members of a kind (Chambers et al., 2008; Gelman et al. 2002), and more *central* to what it means to be a member of that kind (Cimpian & Cadena, 2010; Cimpian & Erickson, 2012; Cimpian & Markman, 2009, 2011; Cimpian et al., 2012; Hollander et al., 2009). For example, when asked to explain generic properties (e.g., *birds* have rocks in their stomachs), preschool children invoke important causal functions that those properties serve for the kind, but tend to explain specific properties (e.g., *this bird* has rocks in its stomach) in terms of more external, accidental events or causes (Cimpian & Cadena, 2010; Cimpian & Markman, 2009). Children also seem to understand that generic language has the power to quickly and efficiently convey important knowledge that others should know (Cimpian & Scott, 2012), and themselves use more generic language in situations where they are expected to teach someone else about the world (Gelman, Ware, Manczak, & Graham, 2013).

1.2.2. Non-linguistic communication

Kind-referring cues such as generic language are indisputably powerful, but how do children evaluate evidence in situations when linguistic cues are absent? Recent work with infants might provide a clue. From the earliest months of life infants are sensitive to cues (e.g., eye gaze, joint attention, infant-directed speech) that distinguish instrumental actions from actions with which an adult intends to communicate information for the child's benefit (see Csibra, 2010; Gergely & Jacob, 2013). Moreover, this sensitivity seems to impact how infants process novel information, for example leading them to attend to more stable, trait-like information such as object identity rather than transient information such as location (Yoon, Johnson, & Csibra, 2008). Further, when 14-month-olds see a person communicatively convey affective information (e.g., disgust) about an object, they treat it as a stable property of the object (Gergely, Egyed, & Király, 2007), and may expect others to react similarly towards it (Egyed, Király, & Gergely, 2013). And communicative cues may lead children not only to attend to stable and semantic information about an object, but also to expect to learn information that is relevant to the kind as whole that is generalizable across time for a given individual (Futó, Téglás, Csibra, & Gergely, 2010).

Csibra and Gergely (2009) argue that these findings are evidence that humans have evolved a mechanism for recognizing and capitalizing on communicative actions, and that infants have a tendency take a "pedagogical stance" towards acts of intentional communication. That is, they infer not only that information being communicated is *relevant* (Grice, 1957; Sperber & Wilson, 1986), but also that knowledgeable adults communicate information in order to teach them important things about the world. In turn, this leads them to treat ostensive, communicative actions as pedagogical demonstrations, conveying information that is important and generalizable knowledge about the world, rather than unimportant or episodic information about a particular individual, or information that may be restricted to a particular time or place. It is worth noting that although the particular cues in question (e.g., eye gaze, joint attention) are merely communicative, and can be used with a variety of communicative intentions in mind, when those cues are then followed by a deliberate action that produces novel information, they also can signal pedagogical intent. We will return to this point in the general discussion, but for the time being will refer to these as pedagogical cues.

Given this early tendency to treat information produced pedagogically as more stable and kind-relevant in infancy, the question we now ask is whether older children may use pedagogical cues in the service of conceptual development. That is, might preschool children construe information conveyed in the context of eye contact, joint attention, or other communicative cues, as licensing the kinds of rich inductive inferences that they make during the acquisition of general knowledge about kinds and categories? Recent empirical work suggests they may. In one study (Butler & Markman, 2012), 3- and 4-year-olds observed perceptually identical evidence that a novel object was magnetic, but produced with subtly different actions: the experimenter *accidentally* used the object as a magnet; did so *intentionally;* or did so *pedagogically* for the child's benefit. When they encountered a set of identical objects, which failed to exhibit the novel property, the 4-year-olds explored those inert objects significantly more, trying to get them to produce the property. This indicates that they had made stronger inductive generalizations about the property when it was demonstrated pedagogically. Analogous effects have also been shown in cases where the general context (e.g., pretend play about animals) suggests an adult might be using her actions to communicate general knowledge (Sutherland & Friedman, 2012, 2013).

1.3. Categorization

1.3.1. The problem of categorization

Preschoolers' sensitivity to when others are deliberately communicating information for their benefit guides their inductive inferences about the generalizability of novel information. But beyond inferring whether a given property generally applies to members of a category, an even more challenging issue is that of inferring whether that property is central to what it means to be a member of that kind. Women generally have long hair, for example, but having long hair is *not* necessarily an important or essential property of being a woman. And televisions are generally made of black plastic, but this is by no means a necessary or even particularly important part of being a television.

To what extent do children grasp this distinction? Although investigating children's categories by looking at their understanding of word meanings is not the only approach (see Diesendruck & Bloom, 2003; Markson, Diesendruck, & Bloom, 2008) to investigating category structure, much of the literature on children's early categorization has come from research on early word learning. How children learn, use, and generalize object labels provides a straightforward and direct way of testing children's understanding of what constitutes a given category, how children's category knowledge is structured, and what inferences they draw based on knowing that individuals belong to the same category (Gelman, 2003; Markman, 1989). Within this label-based categorization approach there has been a longstanding debate about whether children's early word meanings are perceptually-based, referring to collections of individuals that share salient external perceptual features, or whether they are more theory-based, referring to *kinds* that share essential, often unforeseen and nonobvious properties. On the perceptually-based view of early word learning, children's early object labels pick out same-shaped or similar-appearing things, regardless of the kind or taxonomic category these individuals belong to (Imai, Gentner, & Uchida, 1994; Landau, Smith, & Jones, 1988), and what appear as categories for children are purely a collections of individuals sharing similar concrete, perceptual properties (Sloutsky & Fisher, 2004a, 2004b; Sloutsky, Kloos, & Fisher, 2007).

In contrast, on the theory-based view, children's early object labels refer to categories of objects that not only often look alike, but more importantly share other important, sometimes unforeseen properties, such as behavior, internal structure, and function (Booth & Waxman, 2002; Gelman, 2003; Markman, 1989). That is, children's understanding of categories is not simply a description of what properties are associated with a category, but an understanding of which properties are essential for members of a particular category and why. Although children are capable of going beyond perceptual information in making category judgments (cf., Gelman & Coley, 1990; Gelman & Markman, 1986, 1987; Gopnik & Sobel, 2000), there remains intense debate about whether children's early concepts are at their core perceptually-based, and how readily and easily children actually go beyond perceptual features in making category judgments, especially when those perceptual features (such as shape) are fairly reliable indicators of category membership (Cimpian & Markman, 2005; Landau, Smith, & Jones, 1998; Smith, Jones, & Landau, 1996).

The theory-based account of concepts (see Gelman, 2003) argues that the properties of a particular concept are interconnected by a web of causal and explanatory links (e.g., Carey, 1985; Gelman & Koenig, 2003; Murphy & Medin, 1985), and that in an individual's conceptual representation of a particular kind, these features may be organized hierarchically, with features that are more conceptually central playing an essential causal role that enables or allows more peripheral features (Ahn, 1998; Ahn, Gelman, Amsterlaw, Hohenstein, & Kalish, 2000; Ahn, Kim, Lassaline, & Dennis, 2000; Ahn & Luhmann, 2004; Medin & Ortony, 1989). Other work has suggested that concepts are organized in terms of the ways in which certain properties are linked to the category representation. For example, some types of connections (e.g., between being a dog and having four legs) are "principled" in nature, meaning that they license specific inferences both about the property and about the kind to which it applies, while other types of properties (e.g., between being a dog and being brown) are not (Prasada & Dillingham, 2006. Even young children treat such conceptually central[1] properties as having important functions for their kind members, often being explained in teleological terms (e.g., eyes are for seeing, Keil, 1992), and use them to make criterial judgments about whether a particular individual is likely a member of a kind (Ahn, Gelman, et al., 2000).

1.3.2. Categorizing artifacts

This tension, between reasoning about categories in terms of shared perceptual features their members possess and reasoning about them in terms of deeper, conceptually central properties is especially important in the case of human-made artifacts. Artifact categories present a unique cultural learning problem, because unlike natural kinds, artifacts are each created with a specific purpose in mind. While we may tend to think that artifacts can be classified according to their perceptual appearance, the functional purpose of an artifact and its outward appearance often may be only loosely related (see Keil, Greif, & Kerner, 2007). For example, most adults and indeed most children likely know what the typical appearance of a chair is, but our concept of what a chair is cannot be *defined* by its similarity to the appearance of a typical chair, as objects as diverse as beanbag chairs and office chairs are clearly all chairs (Bloom, 1996). Rather, adults may well reason about artifacts in a manner parallel to the way they reason about natural kinds, by appealing to some sort of essence—causally deep and often hidden properties which determine or cause their surface features and how one interacts with them (see Bloom, 1996; Kelemen & Carey, 2007). Moreover, a particularly important issue in reasoning about the conceptually central properties of artifacts is that one needs to distinguish between all the various actions an artifact can afford—its potential uses—and what it is *for* (Dennet, 1989). For example, I can use a chair for any number of things, including as a stepstool or a doorstopper, but that does not change the fact that a chair is *for* sitting on, and if I cannot sit on it then it is not a very good chair.

Adults seem to reason about artifacts in this way (German & Johnson, 2002; Kelemen, 1999; Matan & Carey, 2001; Rips, 1989). What about children? The evidence appears mixed. Children as young as 2 seem capable of using a demonstrated function to assess category membership—at least on lexical extension tasks in which they have to generalize a novel label (e.g., Kemler Nelson, 2000; Kemler Nelson, Russell, Duke, & Jones, 2000). In some cases they may use function to categorize even when it is pitted against surface appearance. But this appears to be the case only when the artifact is clearly functionally affordant for the task (Kemler Nelson et al., 2000), and it thus appears plausible that the object has a particular appearance because it was designed to perform that particular function (Asher & Kemler Nelson, 2008). However, in many other studies children appear to ignore function in favor of salient perceptual properties, especially when there is no clear connection between object shape and function (Landau et al., 1998; Smith et al., 1996).

What about reasoning about intended function versus current use? For example, in one study (German & Johnson, 2002) 5-year-olds heard a story in which an artifact was created for one function, given away, and then intentionally used for a different function. The results were mixed: 5-year-olds correctly inferred that the object should be given the kind label that aligned with its intended design, but were at chance in judging which function the artifact was "really for." In another study (Kelemen, 1999), participants were told about novel artifacts that had been intentionally designed to perform a particular function (e.g., squeezing lemons), and were then either intentionally or accidentally used for a different function (e.g., picking up snails). Adults and 4- and 5-year-olds were reliably above chance at judging that the artifacts were *for* their originally intended function. In contrast, 3-year-olds were at chance in terms of weighing intentional design and current use. Four-year-olds can also infer intended function from appearance in some cases. For example, they infer that a cup-like object with another functional property (e.g., a metal-ringed hole in the bottom) is likely something other than a cup, but not if that property does not appear intentionally designed (e.g., an accidental crack; Kemler Nelson, Herron, & Morris, 2002). Four-year-olds also fail to imitate an actor who uses a physically suboptimal tool (DiYanni & Kelemen, 2008), and can even infer intended, designed function from evidence for physical properties produced by their own open-ended exploration (Kelemen, Seston, & Saint Georges, 2012). Taken together, this evidence suggests that by 4 children are capable of reasoning about artifacts in terms of their indented functions, at least in cases where there are relatively clear connections between physical affordances and intended design or construction.

1.4. The current research

1.4.1. Our proposal

As we have seen previously, children use linguistic cues to gauge whether novel information is generic, and this includes inferences of exactly the kind we are discussing here—inferences about whether information is conceptually central to a kind (Cimpian & Cadena, 2010; Cimpian & Markman, 2009; Hollander et al., 2009). We now return the question of whether children might be able to make analogous inferences about whether information is conceptually central based solely on their recognition that information is being deliberately manifested for their benefit.

Why might we expect that recognizing that an adult is explicitly demonstrating a novel function might impact children's inferences about whether that function is conceptually central to the category? The answer lies in the distinction just discussed of intended design versus current use. Clear physical cues that indicate intentional design and construction can certainly license inferences about intended function—but what about instances in

[1] Note that the terms "causally central" (e.g., Ahn, Gelman, et al., 2000) and "principally connected" (Prasada & Dillingham, 2006) are used to argue for different views of children's theory-based categorization. Nevertheless, they make similar predictions about whether properties would be viewed as criterial for category membership. Rather we will use the term "conceptually central" to encompass both possible interpretations.

which physical affordance and function are not so closely linked (e.g., remote controls, magnets, computers)? Witnessing someone intentionally *use* an artifact for a particular function provides reasonably good evidence that this *might* be its original, intentionally designed function, and that it *might* belong to a category of artifacts designed for a similar purpose. And certainly, repeated exposure to this use will likely result in fairly successful construction of accurate artifact representations (cf., Wohlgelernter, Diesendruck, & Markson, 2011). However, we propose children may well distinguish between an adult intentionally using an artifact for a particular function and an adult pedagogically demonstrating that it has that function, and use that distinction to guide their inferences about the conceptual centrality of a particular function to a novel artifact category.

Using an artifact in a particular way is not a guarantee either of its efficacy or of its intentional design. Thus if the implicit goal when reasoning about a novel artifact is to identify its intended function, then attending solely to whether it is used for a particular function may not be sufficient, especially in cases where form and function are not so clearly related—when the learning problem is opaque (Keil et al., 2007) and when the evidence is sparse. Moreover, as children construct *categories* of artifacts, the question becomes not one of whether a particular object was designed for a particular function, but rather whether a particular *kind* of object was designed for and generally can be used for that function. Thus children may well be looking for generic information that is relevant to the category as a whole. Further, we have seen that by age 4 children selectively take information that is conveyed using ostensive, communicative cues to be generalizable (Butler & Markman, 2012). Given this, it seems likely that as children begin to form a more mature, adult-like "design stance" towards artifacts during the later preschool years (see Kelemen & Carey, 2007), they might pay particular attention to when an adult is deliberately communicating something about an artifact, and treat this information as reliable evidence that this is what that kind of artifact is for. In contrast, even when they see an adult intentionally use an artifact in a particular way, they may be conservative about whether that function truly represents the purpose of that kind of artifact. In turn, if they do not infer that the artifact is meant to perform the witnessed function, they may instead judge category membership on the basis of salient perceptual cues. This conservatism may allow children to categorize novel objects in a sensible way, while remaining open to further, better evidence about what that artifact category is truly for.

1.4.2. The current approach

In three experiments we asked whether children would use pedagogical cues to guide their reasoning about what properties are more conceptually central to a novel artifact category. In particular, will children radically reorganize the structure of their incipient category understanding—from a category based on salient perceptual features, to one based on deeper, functional properties—purely on the basis of whether a function is deliberately demonstrated for their benefit? The logic of this argument is that when there is a clear perceptual basis on which to categorize novel objects, children should appeal to non-obvious functional information only if they believe possession of that function to be a central and defining property of the kind.

Thus if children go beyond outward appearances and judge whether a novel exemplar belongs to a category based on whether it possesses a non-obvious function, this would be strong evidence that children view that function as key to kind membership. The question here is whether children will be more likely to infer that if an adult is deliberately demonstrating a novel function for their benefit, it is more likely to be central and defining, compared to seeing the identical function manifested in a perceptually identical and intentional manner, but one that is not seen as done for their benefit.

Moreover, this sensitivity to pedagogical cues may be especially useful in the service of reasoning about artifact function. Indeed, Csibra and Gergely (2009) suggest that receptivity to pedagogical demonstration may have evolved to help in the case of reasoning about opaque knowledge, especially about artifacts. In cases in which children are not tasked with reasoning about a novel function, but rather might be simply wondering how an adult expects them to sort novel objects in a particular context, or which of several perceptual features are likely to be indicative of category membership, children might not so readily privilege pedagogical cues to guide their inferences. We explore this issue in Experiment 3.

2. Experiment 1

In Experiment 1, we asked whether children structure their incipient understanding of a novel kind—as a category based on a salient perceptual feature (color), or one potentially based on a deeper, functional property (magnetism) —purely on the basis of whether the function was deliberately demonstrated for their benefit.

We specifically targeted 4–5-year-olds in this study for two reasons. First, this is the age at which sensitivity to the design stance appears to be developing (see Kelemen & Carey, 2007). Second, although there may well be interesting developmental changes in this capacity (see Gardiner, Greif, & Bjorklund, 2011), by age 4 children clearly distinguish between pedagogical and merely intentional actions in judging how likely properties are to generalize (Butler & Markman, 2012). We introduced children to a novel object deliberately crafted to have no external perceptual cues to its function, so the object's physical affordances could not be used to predict its function. Preschoolers were first taught a kind label ("spoodle") for this object, and then observed perceptually identical evidence that the object was magnetic produced in one of the 3 ways described earlier: accidentally, intentionally, or communicatively and pedagogically. Children were then given a set of objects, half of which were identical to the first one and half of which were another color. Half of the objects of each color were magnetic, while half were not. Children were allowed to play freely with the objects and were asked to sort the objects into spoodles and non-spoodles. This task presented children with two options. They could either judge the category membership of each object on the basis of salient, but superficial, perceptual similarities and differences (whether or not it shared the color of the first object), or they could actively test whether or not each object possessed the hidden property of the first object (magnetism), and categorize each object according to whether or not it performed that function.

2.1. Method

2.1.1. Participants

Forty-eight children participated (M_{age} = 4 years, 8 months; Range = 4;0–5;3). Participants were randomly assigned, 16 per condition, equating for gender and age. An additional 6 children were excluded: 3 because of experimenter error, and 3 because they did not engage in the sorting task and thus provided no usable data (2 in the pedagogical condition, 1 in the accidental condition).

2.1.2. Materials

The materials were 17 wooden blocks, each covered with red or blue colored electrical tape, with yellow tape around one end and on the bottom. The demonstration object (blue or red, counterbalanced) had magnetic strips hidden under the yellow end. Of the 16 target objects, 8 were blue and 8 were red. Four objects of each color were magnetic, while 4 were not. Thus, color and function were fully crossed for the target objects.

2.1.3. Procedure

The first phases of the procedure closely followed those used in Butler and Markman (2012). The experimenter first brought out the demonstration object and gave it a novel label, saying, "This is a spoodle." They then presented children with an array of objects including both the target object and four novel unrelated objects (e.g., common kitchen tools). Children were asked, "can you show me the spoodle" on two successive trials. All children successfully indicated the correct object on both trials. Children then engaged in a short distracter task, in which they were shown how to make a house by folding colored paper. This task distanced the manipulation from the necessarily pedagogical word-learning, and provided a plausible cover story for having paperclips on the table.

The experimenter then started to clean up the toys. He put away each of the distractors, then picked up the target object. In the pedagogical condition, he made eye contact with the child, then said, "Look, watch this," and then deliberately placed the object on the paperclips, picking it up with paperclips attached. In the intentional condition, the experimenter deliberately placed the object on the paperclips, but did not make eye contact or establish joint attention with the child. In the accidental condition the experimenter appeared to accidentally drop the object on the paperclips, saying, "Oops!" In all three conditions he then picked the object up with paperclips magnetically attached, looked at it, and said, "Wow!" before placing it on the table with the magnetic side facing the child.

Children were then given the 16 target objects and told, "Some of these are spoodles, and some of these are not spoodles." They were then told they could play with the objects and were asked to put "the ones that are spoodles" and "the ones that are not spoodles" into different boxes. The experimenter left for up to 90 s, after which, if children had not yet sorted all of the objects, he reiterated the task and waited head down until they finished. If children asked multiple times which ones were spoodles, the experimenter told them they could figure it out and decide which ones they thought were spoodles.

2.1.4. Coding

The first author and a second coder, both blind to condition, coded (1) whether children tested at least one of the additional categorization objects, and (2) how they categorized the objects (i.e., how many objects they put in each box on the basis of whether or not it was the same color as the original spoodle, and how many objects they put in each box on the basis of having tested whether or not it possessed the function). Children were coded as testing if they tried to use one or more of the categorization objects to magnetically pick up paperclips, generating at least some evidence about whether they possessed the function. To be coded as categorizing either by function or by color, children had to systematically sort at least 12 of 16 objects on that basis. Nearly all children (85.4%) categorized systematically by either function or appearance. Of the 7 that did not categorize systematically, 1 was in the Pedagogical condition and 3 were in each of the other conditions. Inter-coder agreement on both measures was 100%.

2.2. Results

We used two measures to look at whether children went beyond perceptual appearances and instead categorized the objects on the basis of function. The first was simply to examine overall how many children in each of the three conditions categorized on the basis of function, and how many categorized on the basis of color. Only children in the pedagogical condition categorized based on function

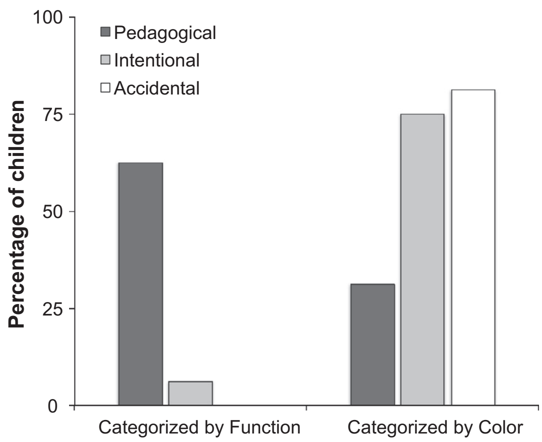

Fig. 1. Results of Experiment 1. Percentage of children in each condition who categorized on the basis of function, compared to the percentage of children in each condition who categorized on the basis of color. N = 48 children (16 per condition).

(see Fig. 1). Ten of 16 children (62.5%) in the pedagogical condition categorized the objects according to whether or not they performed the function, compared with only 1 child in the intentional condition (Fisher's exact test, two-tailed $P = 0.002$) and not a single child in the accidental condition (Fisher's exact test, two-tailed $P < 0.001$). In contrast, children were significantly more likely to sort on the basis of color in the intentional (12 of 16, 75.0%, Fisher's exact test, two-tailed $P = 0.032$) and accidental (13 of 16, 81.3%, Fisher's exact test, two-tailed $P = 0.011$) conditions, than in the pedagogical condition (5 of 16, 31.3%). Thus, virtually all children in the accidental and intentional conditions categorized based on color.

The second measure looked only at children who, in their play with the objects, tested whether at least some of the objects were magnetic. We then asked, of these children, how many went onto use magnetism to distinguish the spoodles from non-spoodles. Children in the pedagogical and intentional conditions were equally likely (75.0%) to explore the objects and generate some functional evidence that could have led them to further explore which objects possessed the function, while children in the accidental condition explored marginally less (43.8%; Fisher's exact test, $p = 0.15$). However, children's use of that information in making category judgments was radically different across conditions. Of the children who tested at least one of the additional categorization objects, 83.3% (10 of 12) in the pedagogical condition used that evidence to categorize the objects, compared to only 8.3% (1 of 12) in the intentional condition (Fisher's exact test, two-tailed $p = 0.0006$) and none (0 of 7) in the accidental condition (Fisher's exact test, two-tailed $p = 0.0007$).

The contrast between the pedagogical and intentional conditions is particularly striking, as in both conditions children witnessed an identical, intentional action in which the adult deliberately used the novel object to magnetically pick up paperclips. Despite this, children viewed that functional property as important and defining of the category only when it was clearly demonstrated for their benefit. This resulted in fundamentally different conceptions of that object kind: as either a category defined by perceptual appearance (color), or one that may be defined by a deeper functional and causal property (magnetism).

3. Experiment 2

In Experiment 2, we conducted an even stronger test of the potential power of pedagogical cues to help children guide their inferences about conceptual centrality. The finding from Experiment 1 led us to ask whether children might profit from their understanding of pedagogical demonstration to go beyond superficial perceptual appearance, even when possession of a deeper causal function conflicts with object shape. The shape of an object is a highly salient feature that is often reliably correlated with category membership. But mature conceptual development hinges on being able to go beyond surface features, including shape, in order to reason about kinds in terms of essential non-obvious properties (Gelman, 2003; Gelman & Wellman, 1991). As discussed earlier, the conflicting roles of object shape and non-obvious object function in early conceptual development has long been a source of controversy (Cimpian & Markman, 2005; Landau et al., 1998).

Experiment 2 pitted possession of the non-obvious function against object shape. Using a slightly streamlined version of the procedure from Experiment 1, we eliminated the accidental condition, focusing specifically on the pedagogical and intentional conditions because this contrast is the most subtle and informative.

3.1. Method

3.1.1. Participants

An additional 32 children participated ($M_{age} = 5$ years, 0 months; Range = 4;4–5;4). Participants were randomly assigned to one of 2 conditions (pedagogical and intentional), 16 per condition, equating for gender and age. An additional 5 children were excluded: 1 because of experimenter error, and 4 because they did not engage in the sorting task and thus provided no usable data. Data from an additional 11 children were lost due to equipment malfunction and the resulting corruption of video files.

3.1.2. Materials

The materials were similar to Experiment 1, but in order to streamline the task children were generally presented with only 12 (rather than 16) objects to categorize. Instead of being half red, and half blue, the objects all had the same colors (blue with green around the bottom end and on the bottom surface of the object) but half of the objects were triangle shaped, and half were rectangle shaped.

3.1.3. Procedure

The procedure was the same as in Experiment 1 except for a few modifications. First, we focused only on the pedagogical and intentional conditions, as the effect of that manipulation was our principal research question. Second, in order to streamline the procedure, children were not explicitly taught the word, but rather learned it non-ostensively. The experimenter said she needed to "find my spoodle," and then searched for it in a bucket, pulling out each of the distractor objects and saying to herself, "that's not it," and pulling out the target object and saying to herself "there's my spoodle, there it is." This eliminated the need for a distractor task, as the word-learning was not pedagogical in nature. The rest of the procedure was the same as in Experiment 1.

3.1.4. Coding

Coding of both measures, (1) whether children tested at least one of the additional categorization objects, and (2) how they categorized the objects, was the same as in Experiment 1. All 32 children consistently sorted by either shape or function. Inter-coder reliability on both measures was 100%.

3.2. Results

On both measures, we replicated the results of Experiment 1, extending the finding to children's reasoning about function versus shape (see Fig. 2). In terms of category

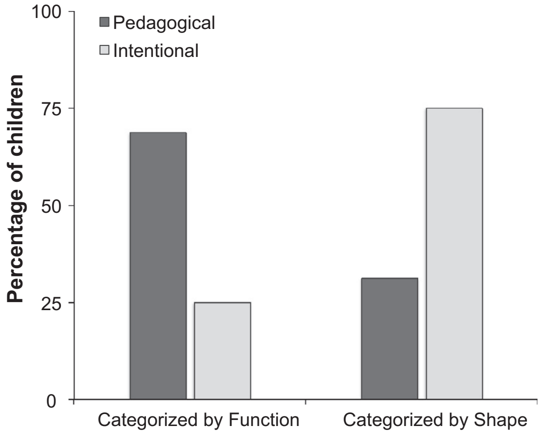

Fig. 2. Results of Experiment 2. Percentage of children in each condition who categorized on the basis of function, compared to the percentage of children in each condition who categorized on the basis of shape. $N = 32$ children (16 per condition).

judgments, 11 of 16 children (68.8%) in the pedagogical condition categorized the objects by function, significantly more than in the intentional condition (4 of 16, 25%, Fisher's exact test, two-tailed $p = 0.032$). In contrast, children were significantly more likely to sort on the basis of shape in the intentional (12 of 16, 75%, Fisher's exact test, two-tailed $p = 0.032$) condition than in the pedagogical condition (5 of 16, 31.3%).

The second measure looked only at children who, in playing with the objects, tested whether at least some objects were magnetic: 13 of 16 children (81.3%) in the pedagogical condition and 10 of 16 children (62.5%) in the intentional condition did so (Fisher's exact test, $p = 0.43$). However, children's use of that evidence again differed across conditions: 84.6% (11 of 13) in the pedagogical condition used that information to categorize, compared to only 40% (4 of 10) in the intentional condition (Fisher's exact test, two-tailed $p = 0.039$).

These results provide further evidence that children use their awareness of whether information is being deliberately demonstrated for their benefit to gauge the importance of that information to their conception of a novel category. Moreover, these results extend that finding to a potentially more critical issue—going beyond basic object shape in order to reason about artifact categories as being defined by the function they were intended to carry out. The results of Experiment 2, like Experiment 1, suggest that children may be conservative when reasoning about whether an intentional use of an object represents the intended, essential function of a novel artifact kind. Observing someone use an artifact in a particular way may not always to be enough for children to judge that function as more centrally important than an object's shape—demonstration is key.

4. Experiment 3

Experiments 1 and 2 provide a clear indication that children are revising their conception of the novel category, from one based on perceptual appearances to one based on nonobvious functional properties, simply on the basis of evidence for that functional property being pedagogically demonstrated for their benefit. In Experiment 3, we further probe the scope of this phenomenon. As we have already discussed, artifacts pose a unique cultural learning problem: distinguishing between current use and intended function. One impact of this is that children might be especially likely to use pedagogical cues to guide their inferences about artifact *functions*, as they act of a tacit guarantee that this is likely what an artifact is truly *for*, but may be less likely to use such cues to guide inferences about other kinds of properties.

To address this question, we used the same methodology as in Experiment 2, but instead of children witnessing a nonobvious functional property, they witnessed evidence for a hidden perceptual property. If children are using pedagogical cues to simply guide their weighting of one cue over another, regardless of what that property is, then we would expect them to show similar patterns of categorization as in Experiment 2. That is, they ought to categorize according to possession of the previously hidden perceptual property significantly more often when it is shown to them in a pedagogical manner. If, however, children are especially likely to use such pedagogical cues to guide their inferences about artifact *functions*, then children simply witnessing an unforeseen perceptual property produced in an intentional manner might show similar patterns of categorization to those children who were deliberately shown the property. We do not have a prediction about whether children will favor one perceptual property over the other—this is something that likely depends on the relative salience of and prior knowledge about various perceptual properties, among other factors. Rather, our prediction is that in the case of discovering an unforeseen arbitrary perceptual property, there may be little difference between the intentional and pedagogical conditions in terms of how children categorize the objects.

4.1. Method

4.1.1. Participants

An additional 32 children participated ($M_{age} = 5$ years, 0 months; Range = 4;8–5;3). Participants were randomly assigned to one of the same 2 conditions as in Experiment 2 (pedagogical or intentional), 16 per condition, equating for gender and age. Three additional children were excluded because they did not engage in the sorting task.

4.1.2. Materials

The materials were identical to Experiment 2, but instead of half of each shape being magnetic, half the objects of each shape were covered in bright yellow tape on the bottom. This property was not immediately visible, but became clearly visible when revealed by the experimenter's action.

4.1.3. Procedure

The procedure was the same as in Experiment 2, with one small change. The actions that produced the evidence were modified slightly to accommodate the hidden perceptual property. In the pedagogical condition, the experimenter made eye contact with the child, said, "Look!", turned the object over so that the yellow bottom was visible both to himself and the child, and said, "Wow!". The intentional condition was identical except that the experimenter did not make eye contact with the child or say, "Look!".

4.1.4. Coding

Coding of how children categorized the objects was the same as in Experiments 1 and 2. All but 4 children (3 in the pedagogical condition, and 1 in the intentional condition) consistently sorted by shape or the color of the bottom. In order to code whether children noticed the presence or lack of this property on the bottom of at least one of the categorization objects, we coded whether they intentionally turned over at least one object and looked at the bottom. Inter-coder reliability was 100%.

4.2. Results

Children in both conditions tended to categorize according to shape. Eleven of 16 children (68.8%) in the pedagogical condition categorized the objects according to shape, compared with 12 of 16 (75%) in the intentional condition (Fisher's exact test, two-tailed $P = 1.00$). In contrast, few children categorized according to the color of the bottom, even when it was deliberately shown to them: 2 of 16 (12.5%) in the pedagogical condition, compared with 3 of 16 (18.8%) in the intentional condition (Fisher's exact test, two-tailed $P = 1.00$).

As in the previous experiments, we then looked specifically at children who, in their play with the objects, looked to see whether at least one of the other objects had a yellow bottom. We then asked, of these children, how many went onto use that property to categorize. Roughly equal numbers of children in both conditions looked to see if other objects had yellow bottoms (9 in the pedagogical condition, 11 in the intentional condition). Children's use of that information in making category judgments did not differ across conditions. Of the children who tested at least one of the additional categorization objects, 22% (2 of 9) in the pedagogical condition used that evidence to categorize the objects, compared to 28% (3 of 11) in the intentional condition (Fisher's exact test, two-tailed $P = 1.00$).

4.3. Discussion

The results of Experiment 3 were clear. In stark contrast to the results of Experiments 1 and 2, when children were faced with the conflict between obvious perceptual features and possession of a previously hidden arbitrary perceptual property, children categorized in the same way regardless of how evidence for the nonobvious property was demonstrated. In both conditions children overwhelmingly sorted on the basis of shape, even when the experimenter showed them the hidden perceptual property in a pedagogical manner.

As we noted earlier, we do not claim that children will never categorize on the basis of some new, previously hidden property. Which of two perceptual properties children use to support categorization is likely to depend on their relative salience, on which children judge to be a more reliable indicator based on past experience, and on other factors. What is important for our purposes, however, is that children did not see information about how or why the evidence was produced (see Schulz, 2012; Shafto, Goodman, & Frank, 2012) as relevant to their category judgments in this case. These results also speak against a alternative explanation for Experiments 1 and 2. If children in the pedagogical conditions of those experiments were simply treating the experimenter's communicative act as an indicator as to how the experimenter wanted or expected them to categorize or play this game, they ought to have done the same here. They did not.

These results suggest that children's sensitivity to pedagogical cues is used flexibly in the service of their conceptual development. Although such pedagogical cues may lead preverbal infants to automatically interpret novel information as generic (Csibra & Gergely, 2009), preschooler's use of such cues to guide their inferences appears more nuanced. Preschool children appear to be selective about when they view the distinction between pedagogical and instrumental action as informative and relevant to solving an inductive problem (as it may be in the case of artifact function), and use this distinction to guide their reasoning in those cases.

5. General discussion

Taken together, these findings illustrate how preschool children flexibly use pedagogical cues to guide their inductive inferences. Specifically, preschoolers assess whether an adult is deliberately demonstrating evidence about a novel object's function for the child's benefit in order to gauge whether that function is likely something central and defining to that novel object kind. In two experiments, children saw identical perceptual evidence that a novel object had a particular nonobvious function (magnetically picking up paperclips), presented in subtly different ways: communicatively for the child's pedagogical benefit, intentionally but without any communicative or pedagogical cues, or accidentally (in Experiment 1). We then asked children to categorize a set of objects and observed whether they based their categories on perceptual features (color, shape) or on possession of the deeper functional property.

The logic was that given a salient perceptual feature on which to base their category judgment, children should go beyond it and categorize according to function only if they viewed that function to be an essential and defining property of the novel kind. The results in Experiments in 1 and 2 were clear: children were significantly more likely to categorize the objects according to function when it had been communicatively demonstrated for their pedagogical benefit. Even when children witnessed identical evidence produced in an intentional manner, but one that was not clearly *for* them, they overwhelmingly categorized the objects using salient perceptual features. The recognition that an action (magnetically picking up paperclips) was done in order to *demonstrate* that function for their benefit seemed to result in fundamentally different conceptions of that object kind: as either a category of objects that is defined by perceptual appearances, or one that may be defined by deeper, functional and causal properties. Importantly, this appears to be especially important in the case of novel functions, for which children need to distinguish between current use and intended function. As Experiment 3 shows, children may not privilege pedagogically demonstrated evidence when that evidence is about arbitrary perceptual properties.

These findings help sharpen our understanding of how children learn from pedagogical acts done for their benefit. According to Csibra and Gergely's (2009) theory of "natural pedagogy," evolutionary pressures led to a communicative system geared towards the transmission of generic knowledge, supported by a constellation of related perceptual and cognitive biases: one for recognizing and attending to faces, eyes, and their actions; one for expecting communication to refer to things in the world; and one for expecting the information being communicated to be generic. The end result is that children are biased to interpret communicative cues as signaling the transmission of generic knowledge. However, and Gergely and Csibra (2009) would agree, the point is not that children always will interpret communicative acts as conveying generic knowledge, merely that they can and are biased to do so. Of course there are many forms of adult communication that are *not* meant as pedagogical teaching of generic information. Cues such as eye gaze and joint attention allow children to identify an act as communicative. But these communicative cues themselves do not specify *what* is being communicated. Consider a scene in which an adult makes eye contact with a child and points at the bottom of an object to show her that the object is cracked or broken. This is clearly a communicative act, using canonical pedagogical cues, but it seems unlikely that a child would take this action as licensing the inference that such objects are generally broken and cracked.

Very young children may well be strongly biased to interpret ostensive communication as conveying generic knowledge (Csibra & Gergely, 2009). But certainly by the time children are 3 or 4 it seems likely that this early sensitivity is employed along with their more general developing social cognitive and pragmatic abilities. At this point the inductive problem becomes one of integrating a variety of sources of contextual information in order to make a pragmatic inference about whether a particular act of communication is meant to convey generic information. Indeed, recent work in the literature on children's understanding of generics suggests that preschoolers are quite capable of this kind of pragmatic reasoning. For example, although there are canonical ways of conveying information in a generic sentence (e.g., using the bare plural, such as "birds fly"), the same construction can also be used to convey non-generic information (e.g., "birds fly by my house every night"). In fact, there is no reliable linguistic marker for generic statements (see Leslie, 2007, 2008). Instead, when faced with a potentially generic utterance, children must make a further pragmatic inference about whether that utterance is meant to convey generic information, and by age 4 can do so by integrating a variety of pragmatic and contextual cues (Cimpian & Markman, 2008; Cimpian, Meltzer, & Markman, 2011; Gelman & Raman, 2003).

In non-linguistic cases children need to reason about similar pragmatic and contextual factors to assess the goal of a particular communicative act, and whether it is likely meant to convey specific or generic knowledge. For example, properties such as "broken" or "cracked," or even intentionally created ones like being yellow on the bottom (as in Experiment 3) are likely not the types of properties that children expect to be important and defining of an artifact kind, even if evidence for these properties is conveyed pedagogically. In contrast, a property like magnetism, as used in the Experiments 1 and 2, is a plausible candidate for an important artifact function, and thus children may be more likely to use their sensitivity to communicative cues to guide their inferences about that function's conceptual importance for a novel artifact kind. We would argue, then, that one contribution of the current findings is to begin to lay the foundation for understanding how it is that preschoolers integrate their early, possibly rigid sensitivity to communicative cues into a context-sensitive set of pragmatic inferences that guide their learning in a flexible, selective manner. A challenge for future research is to map out how children's sensitivity to pedagogical demonstration interacts with various contextual factors, likely to themselves have an impact, such as what kinds of properties and categories are being communicated about, how the categories in question are labeled, as well as with children's developing pragmatic skills.

Our findings also contribute to our understanding of early artifact cognition. As discussed previously, children need to learn how and when to distinguish between the current or various possible uses of an artifact, and its intended purpose or design. Preschool children are just beginning to appreciate this distinction (Kelemen & Carey, 2007), and may be able to use a variety of physical cues to assess intentional design, such as shape, complexity, plausible physical affordances, and others to guide such inferences (Asher & Kemler Nelson, 2008; Kemler Nelson et al., 2000, 2002). It would be interesting to investigate how pedagogical demonstration interacts with these factors to guide children's reasoning, but it is important to reiterate here that physical properties and intended function are not always aligned (Keil et al., 2007), and that in many cases going beyond clear perceptual cues such as shape is a difficult problem for children of this age (Landau et al., 1998; Smith et al., 1996). For these reasons, the current research asked specifically whether children could reason about a function's importance for what it means to be a member of a novel artifact purely on the basis of how evidence for it was produced, without any related cues. The fact that 4- and 5-year-old children make inferences about the conceptual importance of a property to a novel kind, *solely* on the basis of whether functional evidence was produced for their benefit, is striking.

This research illustrates the potential power of pedagogical cues to shape children's learning. Specifically, children recognized that a knowledgeable adult was demonstrating a property of an object for them, and were able to leverage that understanding to construct a conception of a novel artifact category as defined by deeper, shared functional properties, rather than by outward appearances. Our findings connect two distinct literatures: research on early sensitivity to communicative cues in infancy, and research on how older children acquire generic knowledge about kinds and categories from extremely sparse evidence. Connecting these literatures sheds light on how children flexibly use pedagogical cues to guide inferences that are essential to the construction of a conceptual understanding of the world. Our findings show that when evidence is limited, children are conservative about concluding that an observed function is a defining feature of a novel artifact category, and are actively on the lookout for cues that such information is being produced for their benefit in order to guide this inference. Such restraint in learning could be highly adaptive, helping to guarantee that the information that children use to construct their developing concepts is accurate and reliable, supporting further induction, prediction, and explanation about how the world works.

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