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Children consider prior knowledge and the cost of information both in learning from and teaching others

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Abstract

Children are sensitive to whether informants provide sufficient information for accurate learning (Gweon et al., 2011). Do children think that informants should always provide as much information as possible? Here we show that children consider other's prior knowledge and the cost of information to decide how much information is appropriate. We showed children toys that had 20 identical buttons, three of which played music. Given a choice between an informant who demonstrated all 20 buttons (exhaustive informant) or just the three that played music (selective informant), children preferred the exhaustive informant only when the learner was naïve about how many buttons worked and could be misled by a selective demonstration (Experiment 1). Given an opportunity to teach themselves, children were more likely to provide exhaustive information when the learner did not know how many buttons worked on the toy (Experiment 2). These results suggest that young children consider others' prior knowledge to balance the cost and the benefit of information in learning from others and in teaching others.

Keywords: cognitive development, inductive inference, pedagogy, social learning, pragmatics

Introduction

Much of what we know about the world comes from other people. By communicating with others, we easily acquire information that would be difficult, time-consuming, or perhaps even impossible to obtain on our own. However, learning from others is not guaranteed to be effective; we sometimes encounter people who tell us something false, fail to mention something important, or burden us with too much information. Therefore, identifying effective teachers is an important part of learning.

Previous research shows that even young children are sensitive to whether a teacher has provided helpful, reliable information. Children as young as four years of age distinguish informants who provide true and false information and preferentially learn from informants who were previously accurate (Koenig, Clément, & Harris, 2004; Birch, Vautier, & Bloom, 2008). More recent research suggests that children are also sensitive to more subtle forms of misinformation: they evaluate teachers poorly when they provide true but insufficient information. Furthermore, if a teacher previously provided insufficient information (e.g., showing a naïve learner a single function of a toy when the child knew the toy had many functions) children themselves engaged in compensatory exploration when the same teacher showed then one function of a novel

toy (Gweon, Pelton, & Schulz, 2011; Gweon, Pelton, Konopka, & Schulz, *in press*). These results suggest that children's understanding of informant reliability goes beyond simple detection of inaccuracy; what matters is whether the information supports accurate learning.

Children's expectation that teachers should provide true and sufficient information is closely related to Grice's *Maxim of Quantity*, which states that a speaker should be as informative as required in communicative contexts (Grice, 1975; see also Horn, 1984). Recent studies on conversational pragmatics (Barner, Brooks, & Bale, 2011; Katsos & Bishop, 2011) and social evaluation in pedagogical contexts (Gweon et al., 2011; *in press*) suggest that by age five, children appropriately detect and evaluate under-informative informants.

However, the Maxim of Quantity not only states that a speaker should provide sufficient information; it also states that a speaker should provide no more than what is required. One important reason why more information is not always better is that human learners are good at generalizing. Once a child learns what a cup is, she no longer needs others to point out every cup in the world; she can use her existing knowledge to reliably identify cups. Additionally, inferences can be drawn not only from the presence of data, but also from the absence of data. Especially in pedagogical contexts where the informant selects the data for the learner, omission can be surprisingly informative in itself. For instance, when preschoolers are shown just one function of a toy in pedagogical contexts, they not only learn that function, but also infer that the toy does not have additional functions; if there were more functions, the teacher would have demonstrated them (Bonawitz et al., 2011).

It is in fact beneficial that learners can draw inferences from sparse data, because information transfer is often costly. Even just to show how a toy works, an informant incurs a cost for the time and effort involved in generating the evidence, and the learner incurs a cost for processing the evidence. Therefore, we may need to trade the cost of information for the precision and certainty of our beliefs about the world. A rational agent sensitive to such costs should actively resist communicating irrelevant or unnecessary information even when that information conveys something true about the world.

Imagine, for example, that someone shows you a novel toy that has 20 identical-looking buttons. He presses one of the buttons, and the toy plays a musical note. Given your

prior knowledge about buttons (i.e., buttons usually do something), and that all buttons on the toy look identical, you might guess that the rest of the buttons also play a sound. Suppose however, unbeknownst to you, these toys always have only three buttons that play music and the rest are inert. In order for you to learn this the first time, the informant might show every single button on the toy: both those that work and those that don't. However, once you learn that these toys have just a few working buttons, you no longer need to see every single button on a new toy of this kind; observing three buttons that play music is enough for you to reliably infer that the remaining 17 buttons don't do anything. In fact, demonstrating (and observing) 3 buttons is substantially easier and quicker than demonstrating and observing 20 buttons, especially when 17 of them don't do anything exciting. Thus it is not only enough but also more desirable for you as the learner *and* for the informant. This example illustrates that the consequence of omitting information depends on the learner's prior knowledge. A good teacher should consider both the learner's prior knowledge and the cost of information to decide how much information to provide.

Do young children simply expect that more information is always better? Or do children understand that the amount of "sufficient information" can vary with respect to the learner's prior knowledge? In this paper, we ask whether children rationally weigh the cost and benefits of information both in their choice of informants (as learners), and in transmitting information themselves (as teachers). We hypothesize that children consider learners' prior knowledge in deciding how much information is appropriate both when evaluating informants (Experiment 1), and when teaching others (Experiment 2).

Experiment 1

Methods

Subjects 108 children were recruited from a local children's museum (mean age(SD) = 6.45 (0.85), range: 5.06 – 7.98, 59 girls) and were randomly assigned to one of two conditions: Common Ground (N=54, 30 girls) and No Common Ground conditions (N=54, 29 girls). 13 children were dropped and replaced due to parental interference (N=2), experimental error (N=1), or because they were unable to report the difference between the two Toymakers (N=10; see Procedure).

Materials We made four toys from foam board, electrical push-button switches, and simple circuits that played musical tunes. Each toy was a long rectangular tube (32(L) x 3(H) x 3(W) inches, see Figure 1) with 20 push-button switches (henceforth buttons) placed along the top panel. The four toys looked the same except their colors; each toy was colored in red, green, blue, and yellow, respectively. Of the 20 identical buttons on each toy, only 3 were connected to small electrical circuits such that pressing each button played different musical tunes, and the rest of the buttons were inert. The active buttons looked the same

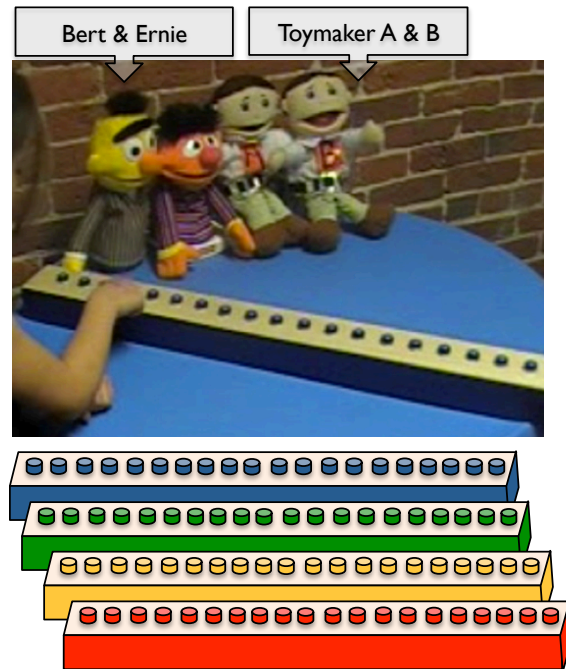


Figure 1. Toys and puppets used in Experiments 1 and 2.

as the inert ones, and the positions of the active buttons varied across toys; thus there was no way to tell which buttons would play music without pressing the buttons.

Two puppets were used as Toymaker A and Toymaker B. The two Toymaker puppets looked identical except that "A" or "B" was written on their ties. Finally, two more puppets (Bert and Ernie) were used as learners who wanted to learn about the toys.

Procedure All participants were tested in a quiet room inside the museum. The experiment consisted of four distinct phases: Introduction, Exploration, Observation, & Choice. The phases appeared in different orders across conditions.

The Common Ground condition started with the Introduction phase, in which the experimenter introduced the Toymakers and the learners (Bert and Ernie) to the participant. The participants were told that the Toymakers knew all about the toys because they made these toys, and that Bert and Ernie were naïve learners who had never seen the toys before but wanted to learn about them.

Then the Exploration phase began. The experimenter pointed to the four toys and said, "When you press the buttons on these toys, they play music. But importantly, not all the buttons work – only some of them play music. Why don't you go ahead and play with this blue toy first?" During the exploration phase, almost all children pressed all the buttons on the toy; if a child missed a button, the experimenter encouraged the child to push it. After the child tried all the buttons, the experimenter asked the child to tell Bert, Ernie, and the Toymaker how many buttons played music on the blue toy. The same Exploration phase was repeated with the green toy.

In the Observation phase, the experimenter said, “Toymaker A and Toymaker B want to show Bert and Ernie how these toys work, but they don’t speak English; they only speak Jabberwocky. Bert and Ernie don’t speak Jabberwocky, so the Toymakers will have to show Bert and Ernie how the toys work” First, children watched as Toymaker A showed Bert the yellow toy, and then Toymaker B showed Ernie the same toy. Importantly, one of the two Toymakers pressed just three buttons on the toy, all of which played music (selective evidence). By contrast, the other Toymaker pressed all the buttons on the toy sequentially regardless of whether they played music or not (exhaustive evidence). Half of the children saw Toymaker A demonstrate selective evidence and Toymaker B demonstrate exhaustive evidence; the other half saw the reverse. After both Toymakers finished demonstrating the yellow toy, children were asked, “What was different about how Toymaker A showed how the toy works and how Toymaker B showed how the toy works?” To pass this question, children had to mention that one pressed all the buttons and the other did not. The same procedure was repeated with the red toy. If a child failed to notice the difference between the two Toymakers even after watching their demonstrations on the red toy, the child was dropped from the analysis.

In the Choice phase, children were told, “See the cabinet over there? It’s full of toys just like these, and you need to learn about them. Which Toymaker would you rather learn from: Toymaker A, or Toymaker B?” The experimenter then held each Toymaker puppet in each hand and kept them equidistant from the child, and did not look at either Toymaker until the child made a choice.

In the No Common Ground condition, the order of the Introduction and Exploration phases were flipped, so that children explored the blue and green toys first and only then were introduced to Bert, Ernie, and the Toymakers. This allowed us to manipulate whether the child, Bert, Ernie, and the Toymakers shared “common ground” about how many buttons work on the toys. In the Common Ground condition, everyone had a strong prior belief that just three buttons worked on these toys; the Toymakers had made these toys (and thus knew everything about them), children had explored some of the toys themselves, and Bert and Ernie watched the child play with them and were explicitly told how many buttons worked. Furthermore, the Toymakers were present during exploration such that they knew what Bert and Ernie learned. By contrast, in the No Common Ground condition, Bert and Ernie never saw the child play with the toys; thus only the child and the Toymakers knew that just a few buttons worked on these toys.

Results & Discussion

Our main measure of interest was whether children chose the selective informant or the exhaustive informant. In the No Common Ground condition, observing the selective evidence might mislead Bert and Ernie who had never seen the toys; buttons usually make something happen, and the

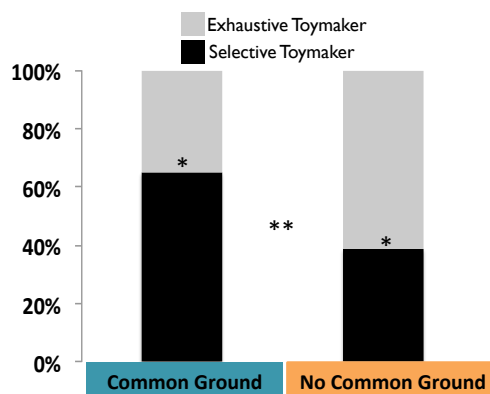


Figure 2. Results from Experiment 1.

learners might infer that all buttons play music from seeing 3 buttons that play music. Therefore, even if it takes a long time and considerable effort to demonstrate all 20 buttons, it makes sense for Bert and Ernie to see all of them. By contrast, in the Common Ground condition, Bert and Ernie had already watched the participant explore the toys, and were explicitly told how many buttons worked on the toys in the presence of the Toymakers. Given that everyone already knew that just a few buttons worked on each toy, observing many inert buttons is not only tedious for the learners but also fails to add much information. Thus we predicted that children in the Common Ground condition would be more likely to choose the selective Toymaker than the children in the Common Ground condition.

As expected, children’s choices of Toymakers differed across conditions; more children in the Common Ground condition chose the Toymaker who pressed just the active buttons than children in the No Common Ground condition (Common Ground vs. No Common Ground: 65% vs. 38%, $p = 0.01$, Fisher’s Exact). Children in the Common Ground condition chose the selective Toymaker over the exhaustive Toymaker significantly above chance ($p = 0.01$, one-sided binomial) whereas the reverse was true in the No Common Ground condition ($p = 0.05$, one-sided binomial).

Although we had no a priori predictions about developmental change, given our wide age range (5 – 7 yrs) we looked at the results after median-splitting the groups by age ($N=27$ in each condition in each age group; median age: 6.6 in Common Ground, 6.5 in No Common Ground). We observed similar effects in both the older and younger groups. In the older group, 70% of children in the Common Ground condition chose the selective teacher compared to 33% of children in the No Common Ground condition ($p = 0.01$, Fisher’s Exact). In the younger group, 59% and 44% of the children chose the selective Toymaker in the Common Ground and the No Common Ground conditions, respectively ($p = 0.04$, Fisher’s Exact).

These results suggest that children don’t simply prefer informants who provide more information; instead, children consider what others know and how costly the information is. When learners already knew that just a few buttons worked, children preferred the informant who was faster and more efficient; when learners knew nothing about the toys,

children preferred the informant who went through the trouble to demonstrate all the buttons. These results were observed even in the youngest participants, suggesting that by six years of age, children consider others' knowledge as well as cost of information to decide whom to learn from.

One interesting question is whether children also consider these factors when they themselves are the informants. There has been some previous work on children's ability to teach others (e.g., Ashley & Tomasello, 1996; Strauss, Ziv, & Stein, 2002). In particular, by age three, children expect a teacher to teach a certain skill (e.g., how to sing) to those who lack the skill rather than to those who already possess the skill (Strauss et al., 2002). If the cognitive capacities that allow us to be smart learners also make us smart teachers, five-year-olds might not only be able to consider what others know, but also flexibly trade-off the costs and benefits of information transmission. Thus in Experiment 2, we manipulated the learners' prior knowledge across conditions and asked children to demonstrate the toys to the learners. Because the results from Experiment 1 suggested that the results hold even in the younger half of the participants, in Experiment 2 we restricted our age range to 5- and 6-year-olds.

Experiment 2

Methods

Subjects 32 children were recruited from a local children's museum (mean age (SD) = 5.82 (0.49), range: 5.0 – 6.9, 13 girls) and were randomly assigned to one of two conditions: Common Ground (N=16, 5 girls) and No Common Ground (N=16, 8 girls).

Materials The same toys used in Experiment 1 were used. Magnetic stripes were attached on the side of each toy so that small magnets could be placed to indicate which buttons worked. An Elmo puppet was used as the learner.

Procedure In both conditions, children were first given the green toy to explore. The experimenter provided minimal guidance during exploration to make sure that children pressed all buttons on the toy. She also provided magnets that could attach to the buttons so children could mark and remember the buttons that played music. In the Common Ground condition, Elmo was introduced immediately after the child explored the green toy, and then the child was allowed to explore the rest of the toys (blue, red, and yellow) while Elmo sat on the table. The child was asked to show Elmo how many buttons worked on each toy after she finished exploring it. In the No Common Ground condition, Elmo was introduced only after the child was done exploring all four toys, and the child was asked to tell the experimenter how many buttons worked on each toy. In both conditions, the experimenter then asked the children to show Elmo how the green toy worked. Thus in both conditions, children had explored all four toys exhaustively, and Elmo had never seen the green toy; the only difference across conditions was whether Elmo had observed the child exploring the three other toys. The experimenter told the

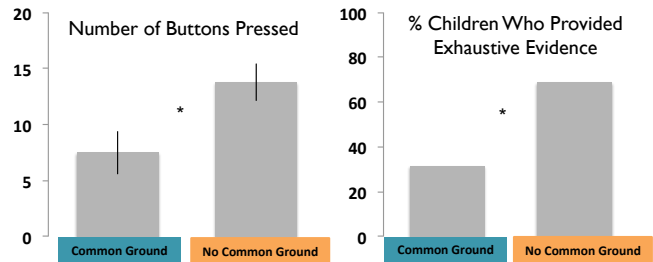


Figure 3. Results from Experiment 2. Left: average number of buttons shown on the toy. Right: proportion of children who provided exhaustive evidence.

child, “Elmo doesn't speak English, he only speaks Jaberwocky. So instead of telling Elmo how the toy works, you will have to show Elmo how the toy works.” Then she placed the green toy between Elmo and the child so that only the child could see where the magnets were. She then walked out of the child's line of sight.

Results & Discussion

In the No Common Ground condition, it made sense to demonstrate all the buttons because Elmo had no prior experience with the toys. By contrast, in the Common Ground condition, it was much less important to show all the inert buttons; since Elmo had already seen three toys where only a few buttons worked, showing just the active buttons would be sufficient for Elmo to infer that these, and only these, buttons played music. Thus if children are sensitive both to the learner's prior knowledge and the costs of teaching, they should demonstrate more inert buttons in the No Common Ground condition than Common Ground condition.

We compared the average number of buttons demonstrated, as well as the proportion of children who provided exhaustive evidence across the two conditions. As predicted, children in the No Common Ground condition demonstrated more inert buttons than children in the Common Ground condition (No Common Ground vs. Common Ground: 13.7 vs. 7.5, $t(30) = 2.45$, $p = 0.02$). This difference was not present in the number of active buttons taught; all children pressed all three active buttons regardless of condition (except for one child in the Common Ground condition who pressed only two). Furthermore, 11 of 16 children in the No Common Ground pressed all 17 inert buttons, while only 5 of 16 children in the Common Ground condition did so (69% vs. 31%, $p = 0.038$, one-sided Fisher's Exact). These results suggest that five and six-year-old children can flexibly decide how much information to provide to a learner by considering what he already knows.

General Discussion

Across two experiments, we showed that children consider both the cost of information and other's prior knowledge both in learning from others and in teaching others. When selective information could mislead the learners, children

not only preferred informants who spent the time and effort to demonstrate every button, but they also incurred costs themselves by pressing more buttons to teach the learners. By contrast, when selective information was enough to support accurate learning, children preferred the informant who quickly showed just the buttons that worked, and they themselves were more likely to press just these buttons to teach the learners.

These results suggest that five and six-year-old children understand principles that underlie cooperative communication. Grice's *Maxim of Quantity* (Grice, 1975; see also Horn, 1984) posits that an informative utterance is one that provides no less than, and no more than, what is required by the listener. Consistent with this, children in our study understood how much information would be inferentially sufficient, but not superfluous, given the prior knowledge of the learner. In the absence of explicit instruction about the learners' epistemic states, children spontaneously considered the shared (and unshared) experience with others to infer what the learners knew, and what the teachers knew the learners knew, about the toys. Thus, consistent with other work on cooperative communication, children seem to be sensitive to contexts that support mutual belief and common ground, (Clark, Schreuder, & Buttrick, 1983) and aware of whether information is relevant to a learner given his prior knowledge (Wilson & Sperber, 2005).

Abundant prior work suggests that children have an early-emerging sensitivity to shared intentionality and mutual knowledge in simple communicative interactions, such as gaze-following and pointing behaviors (see Tomasello, Carpenter, Call, Behne, & Mall, 2005 for a review). More recent work suggests that preschoolers readily use culturally shared knowledge (e.g., word label) to resolve referential ambiguity (Liebal, Carpenter, & Tomasello, 2013). Our results complement this prior work by showing the sophistication of children's understanding of cooperative communication. Going beyond simple heuristics such as more is always better; they understand that good teachers are those who provide as much information as necessary for accurate learning.

Previous studies also suggest that pedagogically demonstrated evidence can place strong constraints on children's inferences; when a teacher shows one of four functions of a novel toy, they infer that the toy has just one function (Bonawitz et al., 2011). In light of this finding, one might wonder why children didn't simply expect learners to always infer that just three buttons work after observing the selective evidence. The key differences in our study were that the affordances were familiar buttons (rather than non-obvious affordances, as in Bonawitz et al., 2011) and the demonstrated parts (3 active buttons) and the rest of the parts (17 inert buttons) were perceptually indistinguishable. Thus evidence that some buttons worked supported strong inductive generalization to the rest of the buttons. Indeed, previous research shows that given pedagogical demonstration of an object property, children readily

generalize the property to exemplars of the same category (Butler & Markman, 2012). Collectively these results reveal the sophistication of children's inferences from socially transmitted information; the scope of inductive generalization depends not just on the face value of information per se, but also on the learner's prior knowledge and the communicative context (see also Gweon, Tenenbaum, & Schulz, 2010). Such seamless orchestration of cognitive capacities – the ability to generalize from observable features of evidence, to draw inferences that are sensitive to how evidence is sampled, sensitivity to the costs of actions for other agents, and understanding of others' unobservable mental states – is a significant challenge, and future studies should further investigate the complex interplay of these capacities in early childhood.

Children in the current study considered both the costs and benefits of information. However, understanding exactly how much information is worth incurring a certain cost is not a trivial problem. In real-world communicative contexts, there are many different ways to deliver information (e.g., goal-directed actions, unintentional nonverbal cues, language, etc.) and some can be more efficient than others. For instance, by using language, we can compress many actions into just a few words; rather than pressing all 20 buttons on the toy, we could provide exhaustive information by pressing just the active buttons and saying, "and the rest don't work!" In this case, the cost difference between the selective and exhaustive information becomes negligible, and learners should prefer the one who provides exhaustive information regardless of prior knowledge. We are currently testing this prediction.

Recent computational work has begun to formally characterize the value of information and their inferential consequences in communicative contexts (Frank & Goodman, 2012; Smith, Goodman, & Frank, 2013; Shafto, Goodman, & Griffiths, 2014). The current study suggests that similar analyses can be applied to nonverbal communication (e.g., demonstrations), and we hope that these results will inspire and inform future computational work.

So far we have considered cost as a negative – a learner incurs the cost of processing information (and a teacher of transmitting it) for the precision and certainty of the resulting belief. However, incurring a cost can sometimes have a positive effect on our social evaluations. We tend to be more forgiving towards others' incompetence or ignorance when we know he tried very, very hard. Furthermore, the consequence of costs is also affected by various situational constraints. In our prior work with adults, we found that human adults do not necessarily penalize informants for providing more than required when judging their helpfulness (Shafto, Gweon, Fargen, & Schulz, 2012). In the current study, we emphasized the potentially tedious consequences of getting too much information by making children believe that they were about to learn about many similar toys. Without such instruction, children might have been less concerned about costs.

Even early in life, we consider not just the external, objective costs for actions (e.g., the time and effort involved in pressing buttons) but also subjective costs (e.g., how easy or difficult it is for someone to press buttons) as well as situational factors that amplify or decrease the importance of costs (e.g., whether the agent is in a rush). Future work on this capacity to understand others' actions in terms of their costs and reward will shed more light on how exactly human learners evaluate the benefits and costs of information (see Jara-Ettinger, Gweon, Tenenbaum, & Schulz, *in press*).

Future work might also consider children's understanding of opportunity costs. It takes time and effort to act on the world, and by performing these actions we also give up the time and effort that could instead be spent on other actions. Opportunity costs may be subtle, but they can have a profound effect on our decisions and plans for future actions. It would be interesting to know whether children are sensitive to these kinds of costs as well. However, our current results provide some of the first steps in showing children's ability to evaluate the costs involved in communicating information. Even early in life, children rationally balance the costs of actions and their informative value, in deciding whom to learn from and how to teach others.

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