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Early Understanding of the Division of Cognitive Labor

Donna J. Lutz and Frank C. Keil

Two studies with 3-, 4-, and 5-year-olds ($N = 104$) examined whether young children can differentiate expertise in the minds of others. Study 1 revealed that all children in the sample could correctly attribute observable knowledge to familiar experts (i.e., a doctor and a car mechanic). Further, 4- and 5-year-olds could correctly attribute knowledge of underlying scientific principles to the appropriate experts. In contrast, Study 2 demonstrated that 3-, 4-, and 5-year-olds have difficulty making attributions of knowledge of scientific principles to unfamiliar experts. A computational analysis in Study 3 indicated that 4- and 5-year-olds' successes on the first two studies could not be attributed to the way in which words co-occur in discourse. Overall, these studies showed that young children have a sense of the division of cognitive labor, albeit fragile.

INTRODUCTION

As adults, a central part of our daily lives is knowing how expertise is clustered in the minds of others. We routinely make judgments about which people are most likely to have a certain type of knowledge. In the university, this division of cognitive labor is accentuated by formal academic departments, but the same process occurs in any community. At a town meeting, a person might turn to different people for their expertise in law, health, and real estate. In trying to find a new and highly sought after toy for a child, we contact certain people we think are likely sources of leads. In watching a news report, we often evaluate claims in the context of the assumed expertise of the speaker. Granting that all adults in presumably all cultures routinely navigate the division of labor that exists around them, the question arises as to the earliest origins of understanding expertise in the minds of others. The present research tested whether preschoolers are regularly able to think of different adults as having different areas of expertise or whether they are unable to see differences between adults and thereby regard all adults as omniscient.

Although the omniscience perspective has been suggested in the past (e.g., Mossler, Marvin, & Greenberg, 1976; Wimmer, Hogrefe, & Perner, 1988), in this article we argue for the alternative, namely that young children do have notions of a division of cognitive labor among adults that leads to different attributions about what each adult is capable of knowing and doing. This prediction was based on observations of young children as well as on hints in the existing literature. Children with powerful pockets of expertise have been well documented, whether it be in chess, dinosaurs, or video games (Chase & Simon, 1973; Chi, 1978). In many cases, the expertise of preschoolers is so high that they outperform adults. In such cases, views of the omniscient adult cannot thrive. Moreover, children seem to have some early sense of differing occupations, as seen in the inferences they draw when reading children's books about various professions and in their attempts to evaluate their knowledge of professions (Wright et al., 1995).

In a different context, there is a strong assumption that children are able to evaluate expertise in the minds of others, namely in the peer tutoring movement that has swept much of educational practice (Cohen, Kulik, & Kulik, 1982; Fuchs, Fuchs, Mathes, & Simmons, 1997). Children as young as 5 are routinely put into groups of peers in which it is assumed they will be able to assess others' knowledge in the group and how their knowledge might be supplemented. Although there is an enormous body of studies on the efficacy of peer tutoring, there is very little work that asks how children understand expertise—or lack of it—in the minds of others, even though such an understanding would seem to be a necessary part of the peer tutoring process. Even if some knowledge of expertise in others is implicitly revealed through peer tutoring, however, there is a major difference between a 5-year-old's knowing that a peer has not fully grasped some aspect of a lesson that is actively under discussion in a classroom and a 4-year-old's ability to know that adults' long-standing sets of knowledge are clustered in different ways for different sets of adults. Expertise as we normally understand it is different from local lesson mastery, especially when one is viewing the minds of adults.

One purpose of the present research was to document that indeed young children can understand that different pockets of expertise are associated with different individuals. Beyond that general demonstration, several subsequent questions arose, most of which revolved around the issue of how children might conceive of knowledge and skills being linked to individuals. Assuming that children do reliably see different adults as having different areas of expertise, on what bases do they make such inferences? How might they generalize expertise? On the basis of associations to "x"? On the basis of notions about how phenomena are clustered in the world? On the basis of beliefs about expert access to information, or on how knowledge might be unified by a common goal? The present research here represents a step toward addressing these questions.

At the simplest level, one may simply associate typical dispositions with an individual or an occupational category such as "doctor." Thus, a young child might notice that doctors are associated with behaviors in physical examinations (e.g., looking in the ear, listening to one's heart) as well as with certain causal powers (e.g., making earaches get better, fixing broken bones, helping lacerations and abrasions heal). When presented with an individual who knows how to fix broken bones, the child might assume simply through association of behaviors that the same individual is likely to know about how to make earaches go away. At this level, there might be little or no generalization to other roles performed by doctors, but which have not been exposed to the child.

At the other end of the continuum, a child might link epistemology with metaphysics. That is, the child might have intuitive notions about phenomena in the world that are unified by common underlying principles or generalizations. Therefore, the child would generalize expertise not on the basis of prior associations, but on a guess of what underlying principles a person who knows one piece of knowledge must know and what other pieces of knowledge are therefore predicted from knowing those principles. As adults, this approach appears to be used frequently. If told that someone is an expert in why tops stay up, one is more likely to assume that that person has some insight into why projectiles follow parabolic trajectories than why cows have large stomachs. Top and projectile knowledge are clustered together because it is assumed that they both require some insight into laws governing moving bodies, or physical mechanics.

At one level, it seems implausible that young children should be capable of such principle-based inductions about clusters of knowledge. None have heard of physics or mechanics as intellectual areas and none have been explicitly exposed to the principles of Newtonian mechanics. Thus, at the level of explicit knowledge of principles and the use of that knowledge to cluster beliefs in the minds of others, all young children and probably most adults would not fare well. However, the same adults who might not be able to articulate the principles that explain precession in spinning tops might nonetheless have a strong conviction that common or closely related principles govern the motions of solid bodies. Therefore, adults would reason that a person who fully understands one such motion is more likely to understand other such motions than say an aspect of biology. This level of understanding can be thought of as the "common principle" assumption and might well be within the grasp of children as well.

Furthermore, there is now considerable evidence that, in other contexts, preschoolers are able to look for deeper principles that underlie appearances (Gelman & Wellman, 1991; Wellman & Gelman, 1997). Thus, at least, in principle, it is plausible that young children might be sensitive to some of the underlying relations that are responsible for principled domains of expertise.

The present studies were designed to more closely assess where in the continuum between ungeneralizable associations and the common principle assumption young children might lie in their abilities to assign expertise to the minds of others. Preschoolers are of special interest in this regard because they precede any regular school curriculum in which some instruction into domains of understanding may be explicit or implicit in terms of how topics are sequenced in a classroom.

The first area in which notions of expertise could emerge might be in children's understanding of highly familiar professional roles. Those roles thus formed the basis for the first study. The second study examined generalizations from less familiar roles, and the final study was a computational analysis of an attempt to associatively model children's performance in the tasks used in Studies 1 and 2.

STUDY 1

If children have some notion of expertise, it might first emerge with highly familiar adult roles. There is an immense literature on roles conveyed by gender (e.g., Miller & Budd, 1999), but the interest in the present study was not in expertise that comes from the imposition by a culture but rather in expertise that arises from ways in which people understand real-world phenomena. To determine most likely roles, children's books were examined for the most frequently mentioned roles, either explicitly by label or as depicted by text and/or pictures. A doctor was by far the most frequent role. A teacher was another role, but was rejected for this study because teachers often appear to children as experts on a multitude of topics. The view of teachers as more specific experts in the art of pedagogy does not seem to emerge until a later point in development. The other common and clearly distinct role from doctor (e.g., not nurse or dentist) was a car mechanic, often depicted even when not always labeled as such.

Method

Participants. Fifty-six children from the greater New Haven, Connecticut area participated in this study. The children were predominantly White and middle class. The 30 boys and 26 girls were placed into three age groups: 3-year-olds (M = 39.7 months, *range* = 36–47 months; 11 boys, 7 girls), 4-year-olds (M = 53.1 months, *range* = 48–59 months; 8 boys, 11 girls), and 5-year-olds (M = 62.2 months, *range* = 60–67 months; 11 boys, 8 girls).

Test items. The knowledge bases of a doctor and a car mechanic were contrasted. These two occupations were chosen for four reasons: (1) the occupations are familiar to young children; (2) the knowledge bases of the occupations are not very abstract (e.g., as opposed to a lawyer's knowledge); (3) the knowledge bases of the two occupations do not overlap; and (4) the knowledge bases could be easily broken down (e.g., as compared with other occupations such as mail carrier) into three different levels that were called stereotypical role, normal functioning, and underlying principles. Stereotypical role was defined as the knowledge one can observe a doctor or car mechanic using (i.e., items that explore what a doctor does when examining a patient, items that explore what a car mechanic does when working on a car). Normal functioning was defined as knowledge pertaining to the functioning of a larger category (i.e., items that pertain to a doctor's knowledge about the functioning of people, items that pertain to a car mechanic's knowledge about the functioning of machines). Underlying principles were defined as knowledge of the scientific principles that encompass each domain of expertise (i.e., items that pertain to living kinds, other than people, in the domain of biology; items that pertain to phenomena, other than the functioning of machines, in the domain of physical mechanics).

Twenty-four questions were prepared (see Appendix A). Each question was in the form of "Who would know more about [topic]?" Twelve questions pertained to a doctor and 12 pertained to a car mechanic. Within each set of 12 questions, there were 4 stereotypical role questions (e.g., "Who would know more about how to fix a broken arm?", "Who would know more about how to fix a flat tire?"), 4 normal functioning questions (e.g., "Who would know more about why some people are born with red hair?", "Who would know more about how elevators work?"), and 4 underlying principles questions (e.g., "Who would know more about why plants need sunlight to grow?", "Who would know more about whether a ladder is strong enough for a person to climb?"). Thus, out of the 24 questions, there were a total of 8 stereotypical role, 8 normal functioning, and 8 underlying principles questions.

Procedure. Each child was interviewed individually. At the beginning of a session, the child was introduced to a doctor doll and a car mechanic doll and was told what each one does. "This is a doctor. A doctor is a person who helps people when they are sick or hurt and makes sure that people are healthy." "This is a car mechanic. A car mechanic is a person who fixes cars when there is something wrong with them and makes sure cars run well." Then, the dolls were placed directly in front of the child for the remainder of the interview.

Each child was presented with all 24 questions, in one of four random orders. After each question was read, half the children were asked, "A doctor or a car mechanic?" and the other half were asked this question in the reverse order. Because the dolls remained in front of the children throughout the entire interview, the children were given the option of pointing to a doll to express their answer if they did not want to verbally communicate it.

Results

Item type and age effects. For each child, the number of correct answers for each item type (i.e., stereotypical role, normal functioning, and underlying principles) were totaled, thereby providing each child with three scores (see Figure 1 for the means). Three-year-olds performed better than chance only on the stereotypical role items, $t(17) = 2.83$, $p = .01$, whereas the 4- and 5-year-olds performed better than chance on all three item types, 4-year-olds: stereotypical role items, $t(18) = 11.32$, $p < .001$, normal functioning items, $t(18) = 4.82$, $p < .001$, underlying principles items, $t(18) = 2.17$, $p = .04$; 5-year-olds: stereotypical role items, $t(18) = 9.74$, $p < .001$, normal functioning items, $t(18) = 5.94$, $p < .001$, underlying principles items, $t(18) = 4.63$, $p < .001$.

A repeated-measures multivariate analysis of variance (MANOVA), using item type as the repeated measure and age as the between-subjects variable was performed. This analysis indicated a significant

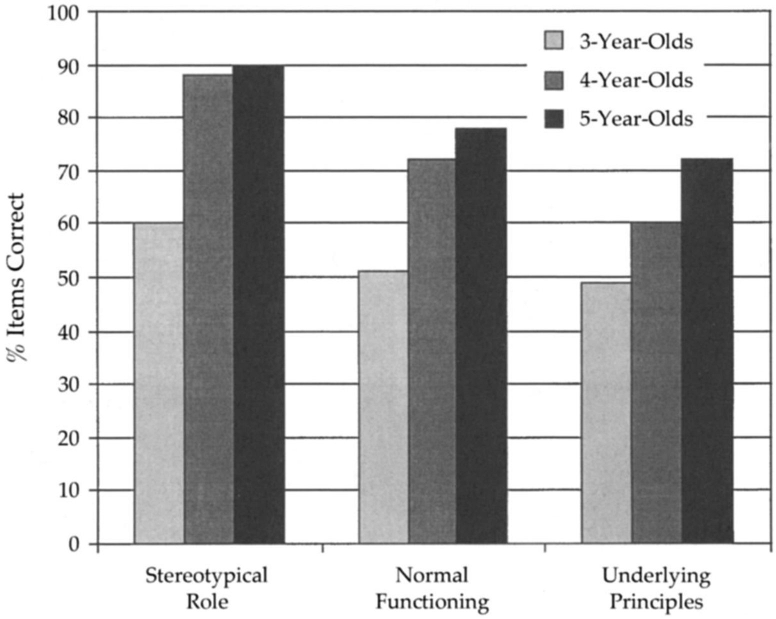

Figure 1 Study 1: children's mean percentage scores as a function of item type.

effect of item type, $F(2, 106) = 31.91$, $p < .001$, $\eta^2 = .38$. Paired-samples t tests collapsed across age were used to further explore differences in performance on the item types. The children found the stereotypical role items to be easier than the normal functioning items, $t(55) = 6.06$, $p < .001$, and the underlying principles items, $t(55) = 6.70$, $p < .001$. They also found the normal functioning items to be easier than the underlying principles items, $t(55) = 2.88$, $p = .006$.

The MANOVA also revealed a significant effect of age, $F(2, 53) = 17.33$, $p < .001$, $\eta^2 = .40$. Bonferroni post hoc analyses showed that 4- and 5-year-olds performed better on the item types than did 3-year-olds, $p < .001$, and 4- and 5-year-olds performed the same, $p = .43$. No interaction between age and item type was found.

A repeated-measures MANOVA was performed to investigate differences in performance by gender. The analysis revealed that males and females performed the same, $F(1, 54) = .01$, $p = .92$, $\eta^2 = .00$.

Item difficulty. To determine whether the doctor items and the car mechanic items were of equal difficulty, post hoc tests were performed, and revealed no differences. There were no differences in the children's performance on the doctor stereotypical role items and car mechanic stereotypical role items, $t(55) = .35$, $p = .726$; the doctor normal functioning items and the car mechanic normal functioning items, $t(55) = .61$, $p = .546$; and the doctor underlying principles items and the car mechanic underlying principles items, $t(55) = -.55$, $p = .585$. Therefore, we were confident that there was no bias toward one profession due to familiarity or other knowledge.

A follow-up analysis of whether some items were particularly influential on the 4- and 5-year-olds' performance on the underlying principles items found that of the eight underlying principles items, two were outside the interquartile range (3-year-olds were not included in this analysis because they did not perform better than chance on the underlying principles items). Eighty-four percent of the 4- and 5-year-olds succeeded on the item, "Who would know more about how to build a tree house?", which was found to be outside the upper end of the range, whereas only 53% of the children succeeded on the item, "Who would know more about whether a ladder is strong enough for a person to climb?", which was found to be outside the lower end of the range. These 2 items were removed and the original MANOVA was repeated. The new analysis showed that there was a significant effect of item type, $F(2, 106) = 104.38$, $p < .001$, $\eta^2 = .66$; a significant effect of age, $F(2, 53) = 17.50$, $p < .001$, $\eta^2 = .40$; and now a significant interaction between age and item type, $F(4, 106) = 3.86$, $p < .006$, $\eta^2 = .13$.

Bonferroni post hoc analyses revealed that the 5-year-olds performed better than did the 3-year-olds, $p < .001$ for stereotypical and normal functioning items and $p < .02$ for underlying principles items, and the 5-year-olds performed the same as did the

4-year-olds, $p > .05$, on all three item types. The 4-year-olds performed better than did the 3-year-olds on the stereotypical role, $p < .001$, and normal functioning items, $p < .002$, but did not perform significantly differently on the underlying principles items with the two outliers removed, $p > .05$. Furthermore, the 3-year-olds did not perform significantly differently from chance, $t(17) = .21$, $p = .83$; 4-year-olds performed marginally significantly better than chance, $t(18) = 1.87$, $p = .07$; and 5-year-olds performed better than chance, $t(18) = 4.03$, $p < .001$, on the underlying principles items with the two outliers removed. It was not surprising, given that 25% of the underlying principles items were removed, to see a minor drop in the pattern of results for the 4-year-olds. This conservative analysis further supported the finding of a clear ability in preschoolers to use deeper principles to cluster knowledge in other minds as well as an improvement in this ability during the preschool period.

Restricted analysis. To further test the children's performance on the items, data for those children who answered fewer than five of the eight stereotypical role items correctly were removed. This more rigorous test was designed to remove data for those children who consistently favored one profession or answered in a random fashion. This analysis reduced the number of participants to 46 children: ten 3-year-olds, eighteen 4-year-olds, and eighteen 5-year-olds. Removing the data for children who answered fewer than five stereotypical role items correctly did not notably alter the pattern of results. There was an effect of item type, $F(2, 86) = 49.33$, $p < .001$, $\eta^2 = .53$; an effect of age, $F(2, 43) = 10.22$, $p < .001$, $\eta^2 = .32$; and no interaction between age and item type, $F(4, 86) = .86$, $p = .49$, $\eta^2 = .04$.

Discussion

Young children have an appreciation that two experts can know divergent information. With age and experience comes the recognition that experts' bodies of knowledge extend further than what is observable. All three groups of preschoolers in the sample of this first study were able to correctly attribute observable knowledge. Further, 4- and 5-year-olds were able to attribute knowledge of underlying scientific principles to the appropriate expert. These children were beginning to cluster biological information and mechanical information into two distinct domains. Presumably, the children could induce that the person who knows about the functioning of people would also know about the functioning of animals and plants, and the person who knows about the functioning of cars would know about the functioning of machines and other artifacts. At the very least, they were able to appreciate that the functioning of artifacts does not cluster with the functioning of living kinds.

STUDY 2

Study 1 showed that preschoolers, to varying degrees, could distinguish expertise in familiar occupations. In the study, the children possibly relied on and responded based on their understanding of what a doctor and a car mechanic know and do. How robust are intuitions about expertise among preschoolers? Would their performance hold when presented with two novel occupations? To assess this question, the same general domains of biology and mechanics were studied, but with experts who did not occupy familiar roles. Instead, they had knowledge of another subarea within biology and mechanics. The role of an "eagle" expert and a "bicycle" expert were used. No children books reviewed showed either kind of expert and discussions with preschoolers after participating in Study 1 suggested that these were indeed novel roles.

Method

Participants. Forty-eight children from the greater New Haven, Connecticut area participated in this study. None had participated in the previous study. The children were predominantly White and middle class. The 16 boys and 32 girls were placed into three age groups: 3-year-olds ($M = 42.5$ months, *range* = 36–47 months; 5 boys, 10 girls), 4-year-olds ($M = 53.4$ months, *range* = 48–59 months, 5 boys, 13 girls), and 5-year-olds ($M = 64.7$ months, *range* = 60–71 months; 6 boys, 9 girls).

Test items. The knowledge bases of an eagle expert and a bicycle expert were contrasted. These knowledge bases were broken down into three different levels, which were called near category, middle category, and underlying principles. Near category was defined as knowledge within the same, narrow category (i.e., eagle expert knowing about the functioning of birds, bicycle expert knowing about the functioning of vehicles). Middle category was defined as knowledge pertaining to the functioning within a larger category (i.e., eagle expert knowing about the functioning of animals, bicycle expert knowing about the functioning of machines). Underlying principles, as in Study 1, were defined as knowledge of the scientific principles that encompass each domain of expertise (i.e., eagle expert knowing about the domain of biology, bicycle expert knowing about the domain of physical mechanics). The underlying principles category was considered to be the same between Study 1 and Study 2. Six of the items in Study 2 were taken directly from Study 1. The remaining two items were changed because the original items asked about animals. In Study 2, items regarding animals fell in the middle category.

Twenty-four questions were prepared (see Appendix B). Eight questions were taken directly from the stimuli in Study 1. Each question was in the form of "Who would know more about [topic]?" Twelve questions pertained to an eagle expert and 12 pertained to a bicycle expert. Within each set of 12 questions, there were 4 near category questions (e.g., "Who would know more about how chickens lay eggs?", "Who would know more about how a steering wheel turns a car?"), 4 middle category questions (e.g., "Who would know more about how skunks can squirt out stuff that makes them smell bad?", "Who would know more about how elevators go up and down?"), and 4 underlying principles questions (e.g., "Who would know more about why plants need sunlight to grow?", "Who would know more about whether a ladder is strong enough for a person to climb?"). Thus, out of the 24 questions, there were a total of 8 near category, 8 middle category, and 8 underlying principles questions.

Procedure. Each child was interviewed individually. At the beginning of a session, the child was introduced to an eagle expert doll and a bicycle expert doll and was told what each one knows. "This person knows all about eagles. He knows all about what kinds of food eagles eat, how many babies they have, and how big they can grow." "This person knows all about bicycles. He knows all about what bicycles are made of, how to fix them if they get broken, and how bicycles' brakes work." Then, the dolls were placed directly in front of the child for the remainder of the interview.

Each child was presented with all 24 questions, in one of four random orders. After each question was read, half the children were asked, "The eagle expert or the bicycle expert?" and the other half were asked this question in the reverse order. Because the dolls remained in front of the children throughout the entire interview, the children were given the option of pointing to a doll to express their answer if they did not want to verbally communicate it.

Results

Item type and age effects. For each child, the number of correct answers for each item type (i.e., near category, middle category, and underlying principles) were totaled, thereby providing each child with three scores (see Figure 2 for the means). Three-year-olds performed better than chance only on the near category items, $t(14) = 4.00$, $p < .001$, whereas the 4- and 5-year-olds performed better than chance on the near category and middle category item types, 4-year-olds:

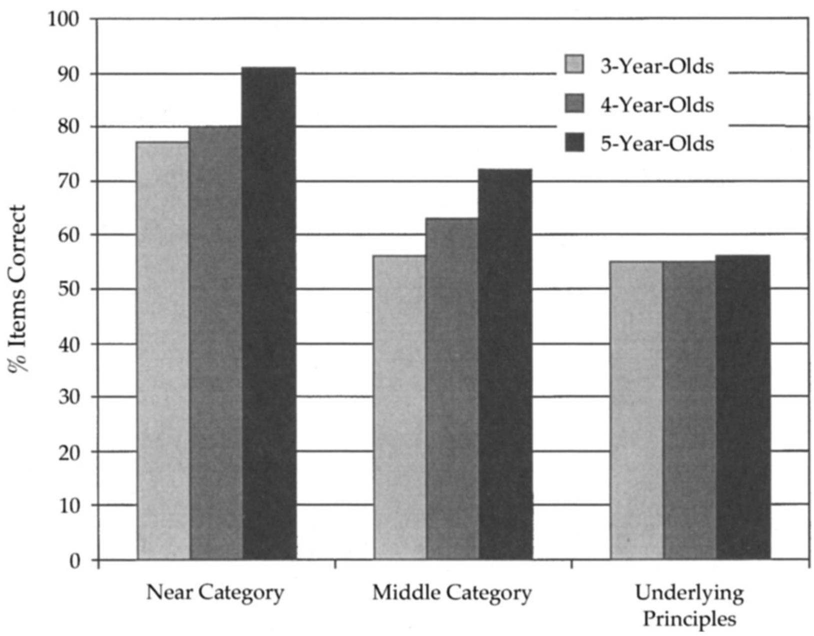

Figure 2 Study 2: children's mean percentage scores as a function of item type.

near category items, $t(17) = 6.71$, $p < .001$, middle category items, $t(17) = 2.22$, $p = .04$; 5-year-olds: near category items, $t(14) = 17.98$, $p < .001$, middle category items, $t(14) = 4.67$, $p < .001$. No age group performed above chance on the underlying principles items.

A repeated-measures MANOVA, using item type as the repeated measure and age as the between-subjects variable was performed. This analysis indicated a significant effect of item type, $F(2, 90) = 34.23$, $p < .001$, $\eta^2 = .43$. Paired-samples t tests collapsed across age were used to further explore differences in performance on the item types. The children found the near category items to be easier than the middle category items, $t(47) = 5.21$, $p < .001$, and the underlying principles items, $t(47) = 7.91$, $p < .001$. They also found the middle category items to be easier than the underlying principles items, $t(47) = 2.81$, $p = .007$. The MANOVA also revealed a marginally significant effect of age, $F(2, 45) = 2.94$, $p = .06$, $\eta^2 = .12$, and no interaction between age and item type.

A repeated-measures MANOVA was performed to investigate differences in performance by gender. The analysis revealed that males and females performed the same, $F(1, 46) = .00$, $p = 1.00$, $\eta^2 = .00$.

Item difficulty. To determine whether the eagle expert items and the bicycle expert items were of equal difficulty, post hoc tests were performed. In the near category items, the children found the eagle items to be easier than the bicycle items, $t(47) = 2.14$, $p < .04$. In the middle category and underlying principles items, the children found the bicycle items to be easier, $t(47) = -3.12$, $p = .003$, and $t(47) = -4.08$, $p < .001$, respectively.

Discussion

All three groups of preschoolers were able to correctly attribute both experts with knowledge that fell into the closest category as their expertise (i.e., the children could report that the eagle expert would know about chickens). Further, the 4- and 5-year-olds were able to correctly attribute both experts with knowledge from a broader category (i.e., the children could report that the bicycle expert would know about elevators). However, no group of children could correctly attribute the scientific principles that underlie each domain of expertise. Here is where the findings of Study 2 differed from those of Study 1.

In Study 2, the children were presented with novel roles, whereas in Study 1, the children were presented with highly familiar roles. Presumably, in Study 1, the children were supported by their previous knowledge of what a doctor and a car mechanic might know and do. This knowledge gave them a framework with which they could cluster pieces of information. Subsequently, when the familiar roles were eliminated, yet replaced by characters with similar expertise, the children's performance worsened.

This decline in performance showed that the children were not simply clustering biological information and mechanical information in Study 1 in isolation. They were taking into account what they knew about the experts' knowledge and using that information as a scaffold for other pieces of knowledge. When the children no longer had prior knowledge about the experts, as in Study 2, they no longer had a structure to help support and integrate these pieces of knowledge. Otherwise, the children would have attributed expertise to the doctor and the eagle expert similarly. Therefore, it was easier for them to appreciate that doctors would know about why apples are sweet than to appreciate that eagle experts would. One way of envisioning the difference is that with a familiar category as the starting point, there are several pointers to a common core of principle-based knowledge, far more than with a novel category. With more converging indicators of the same kind of core knowledge, it is more likely that a young child will be able to sense what that knowledge is.

STUDY 3

The results of Studies 1 and 2 suggest that young children have an insight into common patterns in the world that give rise to surface phenomena. Children seemed to use their metaphysics to inform their epistemology, but a recent advance in modeling of associative information, Latent Semantic Analysis (LSA), suggests that the role of such information as an alternative to having more principled knowledge may have been underestimated. We were interested to see whether the children in the first two studies were using associative relations between words to succeed on the tasks as opposed to deeper principles. To test this proposition, the stimuli from Studies 1 and 2 were analyzed using LSA.

Latent Semantic Analysis is a process that extracts the contextual-usage meaning of words through statistical computations that are applied to a large corpus of text (Landauer, Foltz, & Laham, 1998). The theory driving the method is that the sum of the information about the contexts in which a particular word does and does not appear gives a set of mutual constraints that establishes the similarity of meanings of words and sets of words to each other. The similarity is not simply based on the frequency and co-occurrences of words, but on higher order correlations among correlations. Thus, two words are coded as semantically related not only if they co-occur with each other in a paragraph-size chunk of text, but also if they never directly co-occur but each co-occur with another common word. If, for example, "magnet" and "battery" rarely co-occurred in discourse, but both frequently co-occurred with "electricity," they would be coded by LSA as much more closely related than on the basis of the simple co-occurrence of "magnet" and "battery."

The mathematical representation of a corpus of text is a semantic space that captures the multiple levels of co-occurrence. Within the semantic space, each word and combination of words, including novel combinations, has a multidimensional vector representation. When measuring the similarity between two words in the semantic space, one therefore measures the cosine of the angle between the vectors of the words (Landauer et al., 1998). In Study 3, the semantic space was the college reading level, comprised of texts, novels, newspaper articles, and other information, in various academic and other domains that amounted to a total of 37,651 documents. This college-level corpus was meant to represent the statistical patterns of word relations that a college-educated adult would have encountered. The college-level reading corpus was selected because it provided the strongest measure of any possible relations among words. If there were any information of the sort represented by LSA that guided children's intuitions, the richest representation of information would provide the strongest test of whether children's performance might possibly be based on such statistical patterns. Put differently, if the adult corpus could not predict clusterings made by children, it was even less likely that child corpus could do so.

Method

Procedure, Study 1. The information that was given to the children about each expert, the stems ("This is a doctor. A doctor is a person who helps people when they are sick or hurt and makes sure that people are healthy." "This is a car mechanic. A car mechanic is a person who fixes cars when there is something wrong with them and makes sure cars run well.") and the 24 questions (e.g., "Who would know more about how to fix a broken arm") were entered into LSA. The interest was in comparing each question to each stem.

Results, Study 1. The results of the analysis were divided into two groups of questions. The "same" group compared the questions with their correct answer (i.e., the doctor questions were compared with the doctor stem, and the car mechanic questions were compared with the car mechanic stem), and the "different" group compared the questions with their incorrect answer (i.e., the doctor questions were compared with the car mechanic stem, and the car mechanic questions were compared with the doctor stem). All 24 questions were in each group because each question was compared with the same answer and the different answer.

A Sign Test was used to measure the strength of the association between the words in the question and the words in the stem. The result indicated that the words in the questions were closely related to the words in the stems, $p = .003$; that is, the words in the same questions were more strongly associated with the stems than were the words in the different questions. Because the words in the question could be found in the same discourse as the words in the stem, nothing more than associating the words was needed to succeed on the items. This result was to be expected because the stimuli were designed to include the stereotypical role items that included words that were part of the doctor and car mechanic discourse. The stronger test removed the stereotypical role items, leaving 16 items in each group, and in fact, the words were not closely related, $p = .118$.

These results showed that the 4- and 5-year-olds, who succeeded on the normal functioning and underlying principles items, could not have based their answers solely on the way that words co-occured in discourse. More likely, the children used their metaphysics to inform their epistemology; some set of beliefs about relations deeper than associations were driving their intuitions about how to cluster knowledge in the minds of others. In contrast, 3-year-olds may have simply used lexical co-occurrence because they only succeeded on the stereotypical role items.

Procedure, Study 2. Again, the information that was given to the children about each expert, the stems ("This person knows all about eagles. He knows all about what kinds of food eagles eat, how many babies they have, and how big they can grow." "This person knows all about bicycles. He knows all about what bicycles are made of, how to fix them if they get broken, and how bicycles' brakes work.") and the 24 questions were entered into LSA. The interest was in comparing each question to each stem.

Results, Study 2. The results of the analysis were divided into two groups of questions. The "same" group compared the questions with their correct answer (i.e., the eagle questions were compared with the eagle expert stem, and the bicycle questions were compared with the bicycle expert stem), and the "different" group compared the questions with their incorrect answer (i.e., the eagle questions were compared with the bicycle expert stem, and the bicycle questions were compared with the eagle expert stem). All 24 questions were in each group because each question was compared with the same answer and the different answer.

A Sign Test indicated that the words in the questions were closely related to the words in the stems, $p = .035$. This result was also to be expected because the stimuli were designed to include the near category items. As with the stereotypical role items, the near category items included words that were related to the words in the stems. The stronger test removed the near category items, leaving 16 items in each group, and, in fact, the words were not closely related, $p = .118$.

As before, these results showed that the 4- and 5-year-olds could not have based their answers to the middle category and underlying principles items solely on the way that words co-occured in discourse. However, the 3-year-olds may have used lexical discourse to succeed on the near category items.

Discussion

The results of the LSA analysis indicated that the 4- and 5-year-olds could not have succeeded on the normal functioning and the underlying principles items in Study 1 and the middle category items in Study 2 simply by relying on how words co-occur in language. They must have used a more sophisticated approach, such as generalizing a small piece of information about an expert's knowledge to a broader range of knowledge.

However, to successfully attribute stereotypical role and near category knowledge in Studies 1 and 2, a child did not need a more sophisticated heuristic than lexical co-occurrence. These types of items mapped onto the information the child knew about each expert. For example, the stereotypical role items were about activities that a child could watch a doctor perform in any given day. Therefore, the language in those items was usually included in the language children used to talk about doctors.

GENERAL DISCUSSION

Children as young as 3 years of age already have a sense of the division of cognitive labor. They understand that adults are not omniscient and that they do have different areas of expertise. However, this understanding is limited. Three-year-olds, for example, seem only able to map expertise attributions onto stereotypical roles that are directly associated with a particular kind of expert. They could judge that doctors know more than do car mechanics about how to fix a broken arm and that mechanics know more than do doctors about how to fix a flat tire. Yet, 3-year-olds could not judge who would know more about why some people have red hair or how to fix a broken lawn mower, topics that would lie within broader areas of expertise having to do with domains such as the functioning of humans and machines. Similarly, they were not able to report who would know more about why plants need sunlight to grow or how to build a tree house, topics associated with broader expertise in biology and mechanics. One plausible mechanism here is that 3-year-olds were noting correlations of words in discourse and recognizing that certain key words were more likely to be associated with discussion about doctors and other words were more likely to be associated with discussions about mechanics. The LSA confirmed that this kind of information would be available for drawing such inferences, but only for the stereotypical role items.

With older children, however, a more complex ability to make attributions about expertise emerged. Children as young as 4 years were able not only to make attributions about stereotypical roles but also to make judgments about quite general and seemingly abstract domains such as biology and mechanics. Moreover, they did so in ways that were not apparent to the LSA program, which could not find the clusters that were apparent to the children. In other words, LSA showed that the 4- and 5-year-olds were not merely associating the phrase "some dogs have eight puppies" with the word "doctor" or the phrase "build a tree house" with the phrase "car mechanic" because they had encountered those words or phrases in some pattern of mutual proximity before. Instead, the children appeared to be using deeper, underlying principles to attribute knowledge to the experts.

In other respects, however, 4- and 5-year-olds showed considerable limitations on their ability to envision how knowledge might be clustered in the minds of others. When the experts were not familiar ones but were drawn from the same general domains of biology and mechanics, 4- and 5-year-olds were only able to extend the knowledge to the intermediate level (i.e., animals and machines) and not to the broader disciplines. The attribution to an intermediate level was not discoverable to LSA; but without familiar experts as a base for attribution, these children were not able to extend their knowledge more broadly.

We do not claim that 3-year-olds can only understand expertise in an associative manner, but with the tasks used in these studies, it is not possible to assume that they were using anything beyond associative relations to guide their judgments. In contrast, the 4-

and 5-year-olds were clearly using additional forms of information. In the context of attributing expertise, they saw greater similarities among phenomena within such broad domains as biology and mechanics than among phenomena that cut across these domains. Their ability may be related to a broader set of beliefs that "the domain of living things is foundationally different from that of artifacts." Such beliefs might lead to the expectation that foundational differences arise from different principles that organize the domains and that an expert in those principles should have a greater grasp of the domain as a whole. Much of the literature on the emergence of biological thought in the preschool years would support such a view because children seem to believe that the essences of living kinds and artifacts have different structures and consequences (e.g., Gelman & Hirschfeld, 1999; Hatano & Inagaki, 1994, 1999).

It might be argued that the 4- and 5-year-olds in Study 1 did not need to have principle-based knowledge of living kinds and artifacts, but only needed to know that doctors were experts in living things and car mechanics were experts in mechanical artifacts. Thus, they might have based their judgments on linking those groups of experts with highly abstract categories. This is certainly another way of describing what might have occurred, but it may be less of an alternative explanation than it at first seems. One of the major developments in research on concepts and categories in recent years has been the discovery that much of categorization, especially of more abstract and high-level categories, is mediated by intuitive theories of how and why properties of category members relate (Carey, 1985; Keil, 1989; Murphy & Medin, 1985; Rehder & Hastie, 2001). To have coherent categories of living kinds or mechanical artifacts and to be able to use that knowledge to make judgments seems to require at least a skeletal intuitive theory of what it means to be a living thing or an artifact. What remains is the question of just how much detail is needed to enable preschoolers to make such judgments.

Study 2 provided evidence that children were not merely linking living kinds together and artifacts together in Study 1; the 4- and 5-year-olds were also using background knowledge about these familiar experts. When the occupation labels were removed for Study 2, the children's performance declined. If they were simply linking kinds together without using prior knowledge bases about familiar experts, their performance would have looked similar on both studies. The existence of the familiar expert provided the children with a framework to classify biological and mechanical knowledge into two distinct domains.

The ability to cluster knowledge in the minds of others undergoes considerable development in later years. In the elementary school years, it appears that children come to master finer distinctions such as those between subareas of the natural and social sciences. Even adults can sometimes find it difficult to cluster by underlying principles when various alternatives are introduced, such as clustering by shared lexical items or goal structures (Keil, 2000). The studies presented in this article describe how the ability to think about expertise starts to emerge in the preschool years and may form a basis for what follows later. The central message of these studies is that at least by 4 years of age, children are able to go beyond associative patterns to make their judgments, apparently by using cognitive schema that reflect skeletal notions of key relations that underly abstract categories such as living kinds and mechanical artifacts. These findings then motivate follow-up questions on how notions of expertise develop and connect to ever richer understandings of the world.

The scope of this ability to attribute expertise should be explored by considering a wider range of domains. Because children seem to perform best when one uses highly familiar areas of expertise, the most sensitive tests should involve domains in which the children already have considerable experience with experts in their normal roles. A major challenge is to identify other domains that tap into broad structural regularities in the world. The average preschooler may not have access to many other forms of expertise that are linked to broad classes of phenomena. For example, expertise in Pokemon, although certainly familiar to many preschoolers, most likely would not form much of a basis for broader intuitions about expertise. Very local skills centered around highly specific goals are unlikely to trigger reasoning in children about patterns in the world that underlie phenomena and that would be understood by experts. It may be that natural kinds and artifacts, and the familiar experts who populate those domains, represent one of the most powerful ways in which young children map expert knowledge onto stable patterns in the world. As mentioned earlier, although teachers are familiar to young children, their area of expertise is less clear. For teachers of young children, their expertise is more in pedagogy and in children than it is in the subject matter that they teach; yet because they do teach a wide range of topics it might well seem to a young child that they are experts on everything, especially because the concept of pedagogical expertise might be quite subtle. Other familiar areas of expertise such as firefighters, police officers, and cooks also do not suggest as clear generalization gradients of knowledge. A central question for the future concerns how these various domains of expertise differentiate and become interrelated in the course of development.

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APPENDIX A

STUDY 1 TEST ITEMS

Doctor Items

Stereotypical Role
- Who would know more about why you get a runny nose?
- Who would know more about how to fix a broken arm?
- Who would know more about why you bleed if you scrape your knee?
- Who would know more about how to take your temperature?

Normal Functioning
- Who would know more about why some people wear glasses?
- Who would know more about why some people are born with red hair?
- Who would know more about why you should eat your vegetables?
- Who would know more about why you lose your teeth?

Underlying Principles
- Who would know more about why some dogs have 8 puppies?
- Who would know more about why plants need sunlight to grow?
- Who would know more about why apples are sweet?
- Who would know more about why fish can only live in water?

Car Mechanic Items

Stereotypical Role
- Who would know more about why cars need gas to work?
- Who would know more about what cars are made of?
- Who would know more about how to fix a flat tire?
- Who would know more about what to do if your car won't start?

Normal Functioning
- Who would know more about how to fix a broken lawn mower?
- Who would know more about how to stop a sink from leaking?
- Who would know more about how elevators work?
- Who would know more about how to fix a bicycle?

Underlying Principles
- Who would know more about why some doors need two hinges and others need three hinges?
- Who would know more about how to build a tree house?
- Who would know more about how a yo-yo works?
- Who would know more about whether a ladder is strong enough for a person to climb?

APPENDIX B

STUDY 2 TEST ITEMS

Eagle Expert Items

Near Category
- Who would know more about how chickens lay eggs?
- Who would know more about how parrots open and close their beaks?
- Who would know more about how many bones turkeys have in them?
- Who would know more about how ducks are able to swim?

Middle Category
- Who would know more about why dogs have to stick their tongues out to breathe?
- Who would know more about why people get fevers when they are sick?
- Who would know more about how skunks can squirt out stuff that makes them smell bad?
- Who would know more about why people walk on two legs and cats walk on four legs?

Underlying Principles
- Who would know more about why plants need sunlight to grow?
- Who would know more about why apples are sweet?
- Who would know more about what makes grass green?
- Who would know more about how flowers bloom?

Bicycle Expert Items

Near Category
- Who would know more about how a steering wheel turns a car?

- Who would know more about how the sails on a sailboat stay up?
- Who would know more about why cars with smooth tires can't drive on snow?
- Who would know more about why only trains can run on train tracks?

Middle Category

- Who would know more about what size wheels you need for a lawn mower to work right?
- Who would know more about what makes clothes spin around in a washing machine?
- Who would know more about how elevators go up and down?
- Who would know more about how a construction crane lifts heavy objects?

Underlying Principles

- Who would know more about why some doors need two hinges and others need three hinges?
- Who would know more about how to build a tree house?
- Who would know more about how a yo-yo works?
- Who would know more about whether a ladder is strong enough for a person to climb?

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