Where the Wild Things Are: Informal Experience and Ecological Reasoning

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Category-based induction requires selective use of different relations to guide inferences; this article examines the development of inferences based on ecological relations among living things. Three hundred and forty-six 6-, 8-, and 10-year-old children from rural, suburban, and urban communities projected novel *diseases* or *insides* from one species to an ecologically or taxonomically related species; they were also surveyed about hobbies and activities. Frequency of ecological inferences increased with age and with reports of informal exploration of nature, and decreased with population density. By age 10, children preferred taxonomic inferences for *insides* and ecological inferences for *disease*, but this pattern emerged earlier among rural children. These results underscore the importance of context by demonstrating effects of both domain-relevant experience and environment on biological reasoning.

An important hallmark of human cognition is our ability to generalize information about one class to other related classes. When we learn that A has a novel property, we use what we know about the relations between A and B to compute the likelihood that B will also have the property. Such categorical inductive inferences are ubiquitous in everyday cognitive functioning and, therefore, an issue of central importance in cognitive science (e.g., Hayes, Heit, & Swendsen, 2010; Ranganath, Spellman, & Joy-Gaba, 2010). Moreover, in order to be most useful, categorical inferences must be *selective*; we should utilize different relations to guide inferences in different circumstances.

Most models of category-based induction emphasize the role of taxonomic relations; if we learn something new about DUCKS, it might be reasonable to believe that it would also be true of SPARROWS because the two classes are similar, share specific intrinsic features, belong to the same superordinate class, or all of the above. Such relations have been shown to guide inductive inferences in adults (e.g., Osherson, Smith, Wilkie, López, & Shafir, 1990; Rips, 1975; Shafto, Kemp, Bonawitz, Coley, & Tenenbaum,

2008; Sloman, 1993) and children (e.g., Carey, 1985; Gelman & Markman, 1986; Ross, Medin, Coley, & Atran, 2003; Sloutsky & Fisher, 2004). But taxonomic relations are not the only candidates for guiding inductive inferences; thematic relations—which emphasize contextual, complementary, or causal interactions between entities that co-occur in space and time—can also guide induction. In other words, new information about DUCKS might reasonably be projected to OTTERS because both live in the same kind of habitat, or to FOXES because foxes eat ducks (e.g., Lin & Murphy, 2001; Medin, Coley, Storms, & Hayes, 2003; Ross & Murphy, 1999; Shafto, Coley, & Baldwin, 2007; Shafto et al., 2008). In folk biological thought, the most salient and relevant thematic relations are ecological ones involving shared habitat and predation. In this article, I will focus on the development of selective use of ecological relations to guide inductive inferences about novel properties of living things. I will argue that the degree to which children draw ecological inferences, and the degree to which folk biological inferences are selective, varies with children's environment and their experience with nature.

For adults, ecological reasoning increases with domain-relevant experience. For example, López, Atran, Coley, Medin, and Smith (1997) found that North American university students used taxonomic relations to guide inferences about local mammals, whereas the Itza' Maya of Guatemala utilized ecological relations, and Proffitt, Coley, and

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Medin (2000) found that Chicago-area tree experts reasoning about trees—like the Maya and unlike the U.S. undergraduates—also frequently drew ecological inferences (see Coley, Medin, Proffitt, Lynch, & Atran, 1999; Coley, Shafto, Stepanova, & Baraff, 2005 for reviews). However, few studies have looked at ecological reasoning from a developmental perspective, although there is evidence that other areas of children's biological reasoning are sensitive to differences in domain-relevant experience or environment. For instance, the prevalence of anthropocentric reasoning (the tendency to utilize one's knowledge of human beings to understand non-human living things) seems to be influenced by extrinsic factors such as direct experience with animals, or culture. Inagaki (1990) found that children who raised goldfish were more likely than their counterparts who did not reason about a novel aquatic animal (a frog) by analogy to goldfish rather than by analogy to humans. Likewise, recent evidence suggests that children who differ in cultural beliefs about relations between humans and nature, and presumably in direct experience with nature, also differ in the degree of anthropocentrism evident in their folk biological reasoning (Medin, Waxman, Woodring, & Washinawatok, 2010; Ross et al., 2003; Waxman, Medin, & Ross, 2007). For instance, Ross et al. (2003) found that anthropocentric reasoning increased with development among urban majority-culture children, decreased among rural majority-culture children, and was virtually nonexistent among Native American children. Similarly, Tarlowski (2006) found that children of biological experts were more likely to base biological inferences on the concept ANIMAL than children of laypeople, and that rural children's inferences were more restricted than urban children's. In sum, previous research demonstrates that domain-relevant experience can lead to increases in ecological reasoning among diverse groups of adult experts, and documents differences in children's biological thinking due to relevant experience and environment. However, few if any studies have directly investigated the development of ecological reasoning and how it might interact with either environment, relevant experience, or both.

As argued earlier, to be most useful categorical inferences must be selective; we should utilize different relations to guide inferences in different circumstances. For adults, one source of selectivity is knowledge about the property being projected, which can direct attention to different relations among concepts, and thereby lead to different patterns of inference (Heit & Rubinstein, 1994; Ross

& Murphy, 1999; Shafto et al., 2008). For example, Coley and Vasilyeva (2010) found that property influenced what relations among premise categories college students used to generate inferences in an open-ended format. If told that foxes and rabbits shared a newly discovered gene, participants tended to generate taxonomic projections (e.g., project the gene to other mammals), whereas if told that foxes and rabbits shared a newly discovered disease, participants tended to generate ecological inferences (e.g., project the property to other animals that live in the same habitat, or that eat rabbits). Shafto et al. (2007) not only found a similar pattern of selectivity for adults' inferences about novel genes and diseases but also demonstrated that inferences about disease were predicted by both taxonomic and ecological relatedness between premise and conclusion species, whereas taxonomic relatedness alone predicted inferences about genes. Thus, selectivity is manifest both in the actual inferences that adults make, and in the knowledge that informs those inferences.

Furthermore, among adults, expertise may lead to an increase in selectivity as well as the increase in ecological reasoning discussed earlier. Shafto and Coley (2003) found that when reasoning about marine species, commercial fishermen selectively based projections of novel diseases on ecological relations but based inferences about an unspecified ''property x'' on taxonomic relations. In contrast, undergraduates based their inferences on taxonomic relations for both properties. In sum, for adults, selectivity increases with experience in the relevant domain.

Although one recent debate in cognitive development has centered on the respective roles of similarity and category membership in the development of inductive inferences (e.g., Heit & Hayes, 2005; Sloutsky & Fisher, 2004; Wilburn & Feeney, 2008), few studies have taken a broader view by explicitly examining children's selective use of thematic and taxonomic relations to guide inductive inferences. Kalish and Gelman (1992) demonstrated selectivity among preschoolers' reasoning about artifacts; children projected unfamiliar dispositional properties (e.g., ''will get fractured if put in really cold water'') on the basis of material kind (e.g., GLASS), but projected unfamiliar functional properties (e.g., ''used for partitioning'') on the basis of object kind (e.g., SCISSORS). However, neither object nor material kinds are thematic categories. Nguyen and Murphy (2003) found that by age 7, children could selectively use taxonomic and thematic relations to guide inferences about food; children inferred that

members of the same taxonomic category (e.g., MILK and BUTTER) were likely to have the same kind of ''stuff inside,'' but that members of the same script category (e.g., MILK and COOKIES) were likely to be eaten at the same ''special time.'' Although this shows that by age 7 children are capable of inductive selectivity, it is not clear how domain-general this ability might be, nor how it might vary with domain-relevant experience.

In sum, effective category-based inferences must be selective. In folk biology, adults selectively utilize ecological and taxonomic relations to guide inferences, and this tendency increases with relevant experience. There is ample evidence of children's use of taxonomic relations to guide inferences, and some evidence that children selectively draw different inferences for different properties. But there has been little systematic exploration of the development of category-based ecological reasoning in children, or of the development of selective induction in folk biology. Moreover, despite the importance of comparative work for understanding conceptual development (e.g., Atran & Medin, 2008; Coley, 2000; Ross et al., 2003), no research has investigated how differences in environment or domain-relevant experience may lead to differences in the development of these processes.

In this study, I sought to address these gaps by examining the development of selective taxonomic and ecological reasoning among children growing up in different environments with differing experience with plants and animals. Specifically, I used a forced-choice property projection task to examine whether urban, suburban, and rural children—like adults—selectively generalize properties among taxonomically and ecologically related species. Participants either made inferences about a stable intrinsic property (has stuff inside called ''sarca'') or about a property potentially transmitted through contact or proximity (has a disease called ''sarca''). To measure the degree of relevant experience, children were also interviewed about the kinds of activities they liked to participate in. And to measure perceived relations among the species we asked about, we had adults rate their taxonomic and ecological relatedness.

The research focused on two related questions. First, given the extensive evidence on children's tendency to draw category- and similarity-based inferences, how frequently are children willing to draw inferences to categorically and perceptually dissimilar species that are ecologically related? How does this change with development, environ-

ment, and relevant experience? Based on research with adults, I expected that children with more experience with nature (in terms of living in more rural environments, indicating interest in more nature-related activities, or both) might show more ecological reasoning.

Second, to what extent are children's folk biological inferences selective? In the current forced-choice paradigm, I expected selective induction to involve participants reasoning about stuff inside to favor taxonomic inferences and those reasoning about disease to favored ecological inferences. Selectivity might also involve attention to different interspecies relations for insides versus disease. Of particular interest is the developmental trajectory of selective induction, and whether that trajectory varies with environment. In general, I expected children's inferences to become increasingly selective between ages 6 and 10. Moreover, children growing up in different environments might follow different developmental trajectories. Specifically, based on differences between adult experts and novices described earlier, children from rural environments might show stronger, earlier inductive selectivity.

Method

Participants

Children. Three hundred forty-six children from kindergarten through sixth grade were recruited through elementary schools and after-school programs from 30 communities in Massachusetts. For some of the analyses that follow, children were classified as rural, suburban, or urban based on the population density of the town in which they were living. Although not a direct measure of potentially relevant experience, children from less densely populated areas likely have increased opportunities to interact with plants and animals in relatively intact ecosystems. Likewise, for some analyses, children were grouped by grade into ''6-year-olds'' (Grades K–1), ''8-year-olds'' (Grades 2–3), and ''10-year-olds'' (Grades 4–6). Demographic details are presented in Table 1. Additionally, children were roughly 60% girls and 40% boys; this distribution held in each subgroup.

Undergraduates. Twenty-four Northeastern University undergraduates completed the triad induction task, and another 36 completed the relation verification task. All were recruited from introductory psychology classes and participated for course credit.

Table 1
Demographic Information for Child Participants

Environment (population density)	6-year-olds	8-year-olds	10-year-olds
Rural	$n = 39$	$n = 36$	$n = 36$
Range = 22–434	$M = 6.69$ years	$M = 8.56$	$M = 10.66$
$M = 118$	$SD = 0.63$	$SD = 0.63$	$SD = 0.81$
Suburban	$n = 39$	$n = 46$	$n = 32$
Range = 1,109–8,505	$M = 6.56$	$M = 8.34$	$M = 10.44$
$M = 7076$	$SD = 0.70$	$SD = 0.65$	$SD = 0.66$
Urban	$n = 43$	$n = 41$	$n = 34$
Range = 8,517–15,400	$M = 6.56$	$M = 8.4$	$M = 10.98$
$M = 12,236$	$SD = 1.02$	$SD = 0.79$	$SD = 0.86$

Note. *M* values for the three age groups are given in years.
[a]People per square mile for participants' current town of residence, based on 2000 census figures.

Materials and Design

Activities survey. Prior to the experimental task, each child was given a brief survey about their activities. This involved an open-ended component in which children were asked what kinds of hobbies they had and what kinds of things they liked to do, and focused follow-up questions about activities that could have implications for folk biological reasoning, including pets, gardening, zoos, parks, aquariums, camping, hiking, hunting, and fishing.

Triad induction task Stimuli consisted of 32 8.5 × 11 in. (21.6 × 27.9 cm) laminated cards. Each card contained three realistic color drawings: one premise species and two target species. (examples are presented in Figure 1). One target was taxonomically related to the premise (drawn from the same superordinate category) but ecologically unrelated (e.g., cattail–dandelion or herring–clownfish); the other was ecologically related but drawn from a different superordinate (e.g., cattail–bullfrog [same habitat] or penguin–herring [predator–prey]). Taxonomic targets matched at the superordinate rather than the basic level for several reasons. First of all, a shared label and robust beliefs about members of basic-level categories sharing many properties would likely have led to a strong inferential bias in favor of basic-level taxonomic targets, and it was important to make the two alternatives equally attractive in principle. Second, members of basic-level categories are by definition ecologically as well as taxonomically related, and therefore, were inappropriate for the design. Taxonomic targets occurred on the right for half the items and on the left for the other half; this was counterbalanced across participants. A listing of all triads is presented in the Appendix.
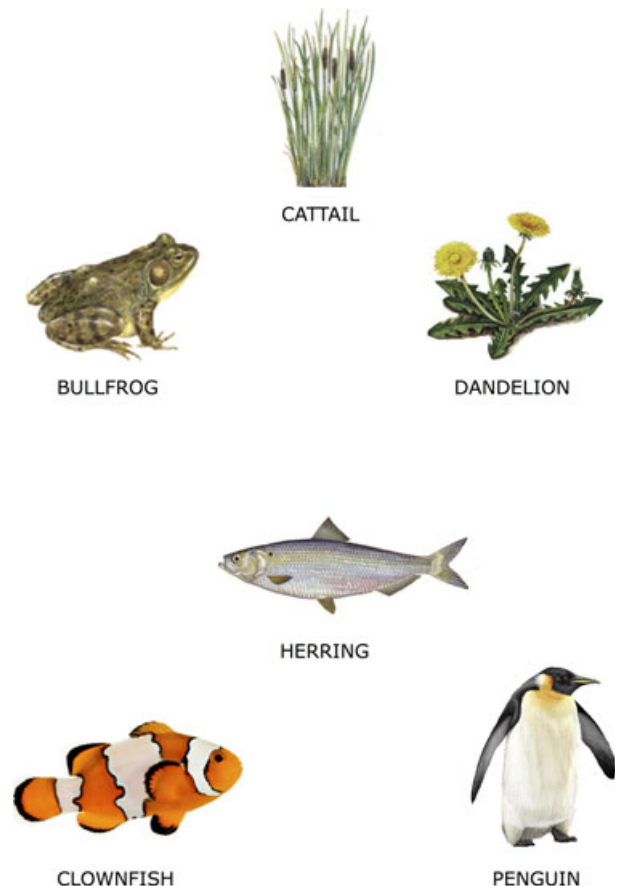

Figure 1. Sample items from triad induction task.

Participants were taught a new property about the premise category, and asked which of the two target species was most likely to share that property. Half of the participants were taught about an internal, pseudoanatomical property (''Has stuff inside called andro''), and the other half were

taught about a hypothetical disease (e.g., ''Has a disease called andro''). Thus, property (disease or insides) was manipulated between subjects. Order of triads was randomized for each participant.

Relation verification task. Ratings of the salience of taxonomic and ecological relations among species in each triad were collected in order to see whether these differentially predicted inferences about disease versus insides. For this task, each triad was broken into two pairs (premise–taxonomic target and premise–ecological target), yielding 64 pairs total. Questions were presented in three blocks; for each block, participants judged the relatedness of each pair with respect to taxonomy, shared habitat, or predation. Order of blocks was counterbalanced across participants, and order of pairs was randomized within blocks for each participant.

Procedure

Activities survey. Children were interviewed individually in a quiet area at their school or after-school program. Prior to the inference task, they were asked a scripted series of questions about their activities. The survey first elicited open-ended responses about activities by asking, ''What hobbies do you have and what kinds of things do you like to do?'' with accompanying follow-up requests for elaboration and encouragement to provide more examples when necessary. Children were then asked about their experience with a standard series of nature-related activities (pets, houseplants, and gardens, and whether anyone has ever taken them to zoos, aquariums, parks, or taken them camping, hiking, fishing, or hunting).

Triad induction task. The inference task was administered individually in a quiet area at a school or after-school program (for children) or a university laboratory testing room (for adults). Children were shown 16 triads each in random order; adults were shown all 32. In the insides condition, for each triad, participants were told: ''There's this stuff called X (using a different nonsense name, e.g., ''sarca,'' in place of X for each triad). Lots of things have X inside. In fact, A's (referring to the premise category) have X inside. Now, do you think B's (referring to one target category) have X inside like A's, or do you think C's (referring to the other target category) have X inside like A's?'' Phrasing for the disease condition was as follows: ''There's this disease called X. Lots of things can get X. Right now, some A's have X. So, do you think B's might get X like A's, or do you think C's might get X, like A's?''

Relation verification task. For this task, stimulus pairs were presented via computer using Superlab 4.0 experiment presentation software (Cedrus Corporation, San Pedro CA, USA). Participants were shown a premise–target pair, asked a question, and responded by pressing keys corresponding to YES or NO. In the taxonomic block, the question for each pair was, ''Do these animals belong to the same biological category?'' For the habitat block, the question was, ''Do these animals live in the same habitat?'' For the predation block, the question was, ''Does one of these animals eat the other?'' The task was self-paced.

Results

Scoring

Activities survey. We developed a coding system to characterize children's responses to the open-ended question about hobbies and things they liked to do. This ultimately included the 14 categories listed in Table 2. Another 9 activities were specifically queried; for each of these 23 categories children were scored a 1 if they indicted that they participated in the activity, otherwise 0.

Triad induction task. For each item in the triad induction task, a participant could either project the property to the taxonomic target (a ''taxonomic inference'') or the ecological target (an ''ecological inference''). Each participant was assigned a score based on the relative frequency of ecological inferences; higher scores represent a greater tendency to project a property to the ecological target. I also examined individual response patterns by classifying each participant as showing a taxonomic or ecological response pattern if they made such inferences on 67% or more of the items; otherwise, participants were classified as showing a mixed pattern.

Relation verification task. This task was scored by item. First, I computed the frequency with which participants in the relation verification task affirmed a taxonomic, shared habitat, or predatory relation for each premise–target pair. Taxonomic relatedness scores were computed for each triad by subtracting the taxonomic relatedness for premise–ecological target pairs from the taxonomic relatedness for premise–taxonomic target pairs. This yielded an index of the degree to which the premise is perceived to be more taxonomically related to the taxonomic target than to the ecological target. Ecological relatedness scores were computed in an analogous fashion except I use the predation and shared habitat relatedness scores, subtracted

Table 2

Component Loadings on Factors Representing Dimensions of Children's Self-Reported Activities[a]

| | Component score coefficient matrix | | | | | | | | | |
| | Factor | | | | | | | | | |
Item	1	2	3	4	5	6	7	8	9	10
Animals[b]		.134	−.112	−.183			.237	−.137		.519[d]
Sports[b]			.187	−.265		.392[d]	−.223	−.212	−.214	.135
TV/Movies[b]					.453[d]					.101
Video & Computer Games[b]							.118	.551[d]		
Card & Board Games[b]				.117	−.160		−.333	.420[d]	−.111	
Reading[b]			.537[d]							
Writing[b]			.316[d]		.261	.250			−.104	
Art/Drawing[b]		.127		−.184			.227[d]	−.133	−.113	−.546
Performance[b]	.128		.281[d]		−.154			−.239	.192	
Outdoors[b]							.519[d]			
Exploring Nature[b]									.616[d]	
Play w/Others[b]	.177	−.175	−.166	−.147		−.298	.239[d]		−.133	.177
Play w/Toys[b]			−.181		.422[d]	.154		.175	.176	−.210
Playground Activities[b]						−.551				
Pets[c]		.445[d]	−.107		−.121			−.172		
Houseplant & Gardens[c]		.475[d]						.154		
Zoo[c]	.301			−.170	.120				−.320	.343[d]
Aquarium[c]	.475[d]									
Park[c]	.300[d]		−.282			.111				−.118
Camping[c]		.297		.316[d]	.179	.169		−.188		
Hiking[c]	.250	.186		.341[d]						
Fishing[c]	.165		.118	.149	−.231	.141	.332	.133	.375[d]	−.161
Hunting[c]		−.110		.556[d]						

[a]Only loadings with an absolute value ≥ 0.100 are reported. [b]Categories derived from spontaneous responses to questioning about hobbies and what kinds of things children liked to do. [c]Items about which children were specifically asked. [d]Each item's highest positive loading on any factor.

ecological relatedness for premise–taxonomic target pairs from ecological relatedness for premise–ecological target pairs for each score, and used the highest resulting relatedness score. This yielded an index of the degree to which undergraduates perceived the premise to be more ecologically related to the ecological target than to the taxonomic target. Although not a perfect measure of *children's* beliefs about relatedness among species, this can be seen as an index of nonexpert adult beliefs about such relations, and therefore, it reflects the folk knowledge of the society in which these children are growing up.

Predictors of Ecological Reasoning

Interpretable responses to all activities questions were obtained from 252 children; these were fairly uniformly distributed between urban ($n = 82$), suburban ($n = 72$), and rural ($n = 98$) participants. Responses were submitted to a principal components factor analysis (using Promax rotation with Kaiser normalization) in order to explore underlying dimensions in the data. This analysis yielded 10 factors with eigenvalues > 1.0, which accounted for 59.7% of the variance in the data. The resulting factors had high face validity, and will be referred to by the highest loading activities. They were, in order of decreasing variance explained, Aquariums & Parks, Pets & Houseplants, Reading & Writing, Hunting & Hiking, TV & Toys, Sports, Outdoors & Fishing, Video & Board Games, Exploring Nature, and Animals & Zoo. The loadings of each activity on each factor are presented in Table 2.

To examine developmental and demographic trends in these activities, we used age and population density to predict standardized scores on each factor via multiple regression. Results are presented in Table 3. Several effects of environment emerged: Scores on the Pets & Houseplants, Hunting & Hiking, and Sports factors (and more weakly, the Outdoors & Fishing factor) all decreased with

Table 3

Summary of Multiple Regression Analyses Using Population Density and Age to Predict Children's Scores on Each of the 10 Activities Factors

Factor	R^2	Standardized regression coefficient (β)	
		Population density	Age
Aquarium & Parks	.024†	−.101	.113†
Pets & Houseplants	.138***	−.380***	.012
Reading & Writing	.062***	.002	.250***
Hunting & Hiking	.088***	−.203*	.209*
TV & Toys	.074***	.017	−.272***
Sports	.064***	−.157*	.193*
Outdoors & Fishing	.019†	−.111†	.080
Video & Board Games	.025*	.057	−.147*
Exploring Nature	.033*	−.097	.150*
Animals & Zoo	.004	.066	.004

†$p < .10$. *$p < .05$. ***$p < .001$.

population density, suggesting that children in more rural environments were more likely to report participation in these activities. There were also numerous age-related effects: Scores on the Sports, Reading & Writing, Hunting & Hiking, and Exploring Nature factors (and more weakly, Aquariums & Parks factor) increased with age, suggesting that older children were more likely to report such activities. In contrast, scores on the TV & Toys and Video & Board Games factors decreased with age, suggesting that younger children were more likely to report such activities. In sum, there were clear age and environmental differences in children's reported activities. In particular, for factors related to folk biological knowledge and experience, scores increase with age and higher scores on these factors were associated with living in more rural environments.

Although it is important to document developmental and environmental differences in children's reported experiences, I was particularly interested in relation between these factors and children's ecological inferences. To examine the effects of age, environment, and nature-related experiences on children's folk biological reasoning, I conducted a multiple regression analysis using standardized scores on all 10 factors, along with age and hometown population density, to predict the relative frequency of ecological inferences among children. Overall, the regression explained significant variance ($R^2 = .108$, $p = .008$), and three factors explained unique variance. These were age ($\beta = .207$, $p = .003$), population density ($\beta = −.150$, $p = .032$), and score on the

Exploring Nature factor ($\beta = .163$, $p = .019$). This suggests that ecological reasoning increases with age, and it also indicates that environment and domain-relevant experience make distinct contributions to the frequency of ecological inferences. Specifically, exploring nature and related activities were associated with more frequent ecological inferences, and independently, living in a less densely populated (i.e., more rural) environment also contributed to increased ecological inferences.

Selective Inductive Inferences

In general, different patterns of inference about disease versus insides would indicate selective induction. Of interest was the development of such selectivity, and in particular, whether the developmental trajectory varied as a function of children's environment. I tested for this in three ways. First, I simply compared the mean relative frequency of ecological inferences for *disease* versus *insides*. Second, I tested whether the distribution of consistent response patterns varied by property. Finally, to determine whether beliefs about interspecies relations differentially influenced inferences about disease versus insides, I used taxonomic and ecological relatedness scores to predict the frequency of ecological inferences via item-wise multiple regressions. In the following, to establish some sense of a nonspecialist adult end state, I present analyses of selective induction in undergraduates. Then, I compare the development of selective induction in rural, urban, and suburban children, and finally, describe development in each environment.

Selective induction in adults. Not surprisingly, undergraduates showed clear evidence of inductive selectivity. Ecological inferences were more frequent among participants' reasoning about disease ($M = 0.71$) than among those reasoning about insides ($M = 0.35$), $t(22) = 4.44$, $p < .001$, Cohen's $d = 1.82$. I also tested for "preference" by comparing cell means to a hypothesized neutral mean (0.5) via one-sample t test. Means reliably > 0.5 indicate a preference for ecological inferences, whereas means reliably < 0.5 indicate a preference for taxonomic inferences. Adult participants' reasoning about disease showed a reliable preference for ecological inferences, $t(11) = 5.04$, $p < .0.001$, $d = 2.07$, and those reasoning about insides showed a reliable preference for taxonomic inferences, $t(11) = 2.17$, $p = .053$, $d = 0.88$.

Adults' distribution of consistent response patterns also differed by property, $\chi^2(2, n = 24) = 10.60$, $p = .005$ (see Table 4). For adults' reasoning about

Table 4
Frequency of Consistent Taxonomic, Ecological, and Mixed Response Patterns for Insides and Disease, by Participant Group

		Response pattern		
Participant group	Property	Taxonomic	Mixed	Ecological
Adults	Insides	6	2	4
	Disease	0	3	9
Rural 6-year-olds	Insides	10	8	2
	Disease	3	6	10
Rural 8-year-olds	Insides	7	7	3
	Disease	1	8	10
Rural 10-year-olds	Insides	6	9	5
	Disease	0	2	14
Urban 6-year-olds	Insides	7	9	5
	Disease	3	13	6
Urban 8-year-olds	Insides	12	9	2
	Disease	4	9	5
Urban 10-year-olds	Insides	7	3	6
	Disease	1	6	11
Suburban 6-year-olds	Insides	5	10	3
	Disease	2	10	9
Suburban 8-year-olds	Insides	13	8	3
	Disease	8	4	10
Suburban 10-year-olds	Insides	7	4	4
	Disease	1	4	12

Table 5
Summary of Multiple Regression Analyses Using Taxonomic and Ecological Relatedness to Predict Item-Wise Mean Ecological Inferences

			Standardized regression coefficient (β)	
Group	Property	R^2	Taxonomic relatedness	Ecological relatedness
Adults	Disease	.432***	−.115	.657***
	Insides	.488***	−.502*	.415*
Rural 6-year-olds	Disease	.212*	−.407*	.162
	Insides	.393***	−.629***	−.175
Rural 8-year-olds	Disease	.314*	−.222	.482*
	Insides	.257*	−.245	.408*
Rural 10-year-olds	Disease	.348*	−.024	.586***
	Insides	.371*	−.447*	.350*
Urban 6-year-olds	Disease	.142	.267	.310†
	Insides	.077	−090	.250
Urban 8-year-olds	Disease	.122	−.302†	.136
	Insides	.071	−.252	−.036
Urban 10-year-olds	Disease	.357*	−.231	.517*
	Insides	.193*	−.303†	.275
Suburban 6-year-olds	Disease	.087	−.010	.294
	Insides	.059	−.174	.145
Suburban 8-year-olds	Disease	.230*	−.406*	.199
	Insides	.144	−.378*	−.122
Suburban 10-year-olds	Disease	.238*	−.047	.478*
	Insides	.410***	−.580***	.197

$^\dagger p < .10$. $^* p < .05$. $^{***} p < .001$.

disease, consistent ecological response patterns were more frequent than expected and consistent taxonomic patterns were less frequent than expected. In contrast, for adults' reasoning about insides, consistent taxonomic patterns were more frequent than expected and consistent ecological patterns were less frequent than expected. (Here and throughout the article, adjusted standardized residuals are used to locate specific effects within significant chi-square analyses; absolute values ≥ 2 are considered notable.)

Finally, adults recruited different knowledge to guide inferences about disease versus insides (see Table 5). Specifically, taxonomic and ecological relatedness both predicted adults' reasoning about insides, whereas only ecological relatedness predicted adults' reasoning about disease. For both adults and children, taxonomic relatedness when significant was associated with fewer ecological (i.e., more taxonomic) inferences, whereas ecological relatedness when significant was associated with more ecological inferences.

Development of selective induction. The development of selective induction, and in particular, whether the developmental trajectory varied as a function of children's environment, is of central interest in this article. If children, like adults, are selective in their willingness to draw ecological inferences, then we should see different inference patterns for children's reasoning about insides versus disease. If selectivity emerges over time, this property effect should be stronger among older children. And if environment influences developmental trajectory, then the timing of this emergence should vary for urban, suburban, and rural children. In other words, this hypothesis posits a three-way interaction. As an initial step in assessing whether children's selective reasoning developed differently in different environments, I ran a general linear model that assessed whether the three-way interaction of Property (insides, disease) × Age Group (6-year-olds, 8-year-olds, 10-year-olds) × Environment (rural, suburban, urban) explained significant variance in the relative frequency of ecological inferences. Results were positive, $F(17, 328) = 5.31$, $p < .001$, $R^2 = .216$, suggesting that the development of selective induction does indeed differ in different environments.

To explore these differences, I first present direct environmental comparisons of the relative frequency of ecological inferences at ages 6, 8, and 10,

respectively. I then present more detailed characterizations of the developmental trajectory of selective induction within each population separately.

Environmental differences in selective induction. In order to directly compare rural, suburban, and urban children at each age with respect to selective inferences about disease versus insides, I performed separate Property (insides, disease) × Environment (rural, suburban, urban) factorial analyses of variance on mean ecological inferences for 6-, 8-, and 10-year-olds, respectively. Results are depicted in Figure 2.

Six-year-olds: When considered together, ecological inferences were more frequent for 6-year-olds' reasoning about disease ($M = 0.58$, $SD = 0.22$) than for those reasoning about insides ($M = 0.42$, $SD = 0.23$), $F(1, 115) = 17.46$, $p < .001$, $\eta_P^2 = 0.13$. How-

ever, as depicted in the top panel of Figure 2, selectivity varied by environment, as confirmed by a property by environment interaction, $F(2, 115) = 2.90$, $p = .059$, $\eta_P^2 = 0.05$. Specifically, comparison of ecological inferences for disease versus insides showed that selectivity was strong among rural 6-year-olds, $t(38) = 3.71$, $p = .001$, $d = 1.20$; weaker but reliable among suburban 6-year-olds, $t(37) = 2.40$, $p = .021$, $d = 0.80$; and absent among urban 6-year-olds, $t(44) = 0.65$, $p = .521$.

Eight-year-olds: Overall, ecological inferences were more frequent for 8-year-olds' reasoning about disease ($M = 0.56$, $SD = 0.27$) than for those reasoning about insides ($M = 0.35$, $SD = 0.26$), $F(1, 117) = 18.48$, $p < .001$, $\eta_P^2 = 0.14$. For 8-year-olds, selectivity no longer varied by environment, although as depicted in Figure 2, ecological inferences were
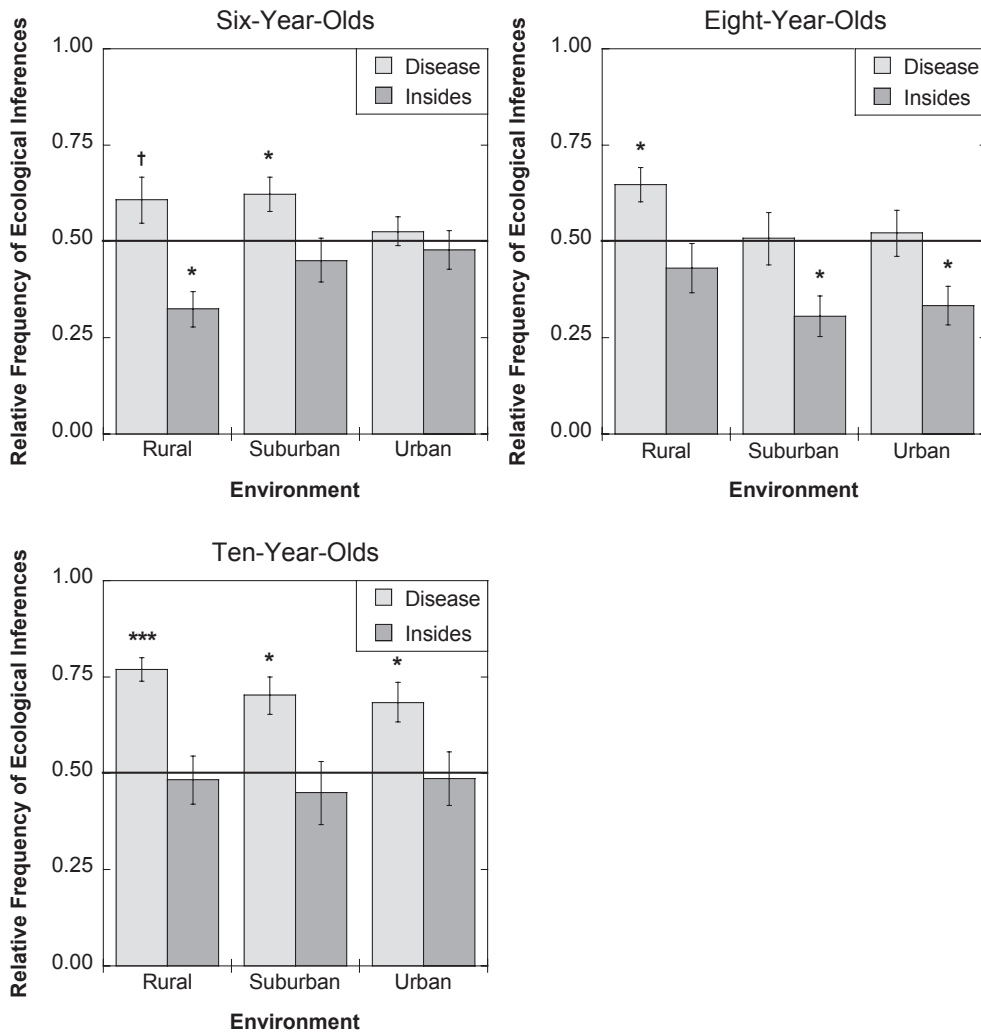

Figure 2. Mean relative frequency of ecological inferences for 6-year-olds, 8-year-olds, and 10-year-olds.
Note. Mean differs from 0.50 at $^\dagger p < .10$, *$p < .05$, ***$p < .001$.

more frequent for rural children than for suburban or urban children, $F(2, 117) = 2.92$, $p = .058$, $\eta_p^2 = 0.05$, LSD $p < .05$.

Ten-year-olds: Among the oldest children tested, ecological inferences were more frequent for children reasoning about disease ($M = 0.72$, $SD = 0.19$) than for those reasoning about insides ($M = 0.47$, $SD = 0.29$), $F(1, 96) = 25.49$, $p < .001$, $\eta_p^2 = 0.21$. By age 10, any environmental differences in relative frequency of ecological inferences had disappeared.

Development of selective induction within each population.   In order to present a more nuanced picture of development among children in each environment, I analyzed changes in selectivity with development for each population separately. To do so—in addition to examining the mean relative frequency of ecological inferences for disease versus insides—I looked at whether the distribution of consistent response patterns varied by property and whether beliefs about interspecies relations differentially influenced inferences about *disease* versus *insides*. These analyses reveal distinct patterns of development among children in each environment.

Rural children: These children showed early, clear, and consistent evidence of inductive selectivity. First, as noted earlier, the relative frequency of ecological inferences was higher among rural children's reasoning about disease than among those reasoning about insides at all ages. Moreover, at age 6, rural children showed a reliable preference for taxonomic inferences about insides, $t(19) = 3.81$, $p = .001$, $d = 1.75$, and a marginal preference for ecological inferences about disease, $t(18) = 1.79$, $p = .091$, $d = 0.84$; they also had a reliable preference for ecological inferences about disease at ages 8, $t(17) = 3.49$, $p = .003$, $d = 1.69$, and age 10, $t(17) = 9.08$, $p < .001$, $d = 4.40$.

Second, rural children's consistent response patterns differed for *disease* versus *insides* at all ages (see Table 4). Specifically, like adults, consistent ecological patterns were frequent for *disease* and rare for *insides*, whereas consistent taxonomic atterns were frequent for *insides* and rare for *disease*—6-year-olds: $\chi^2(2, n = 39) = 9.37$, $p = .009$; 8-year-olds: $\chi^2(2, n = 36) = 8.25$, $p = .016$; 10-year-olds: $\chi^2(2, n = 36) = 14.45$, $p < .001$.

Finally, at all ages, rural children's inferences were systematically predicted by premise–target relations, although not differentially so until age 10 (see Table 5). Specifically, for rural 6-year-olds, inferences about both disease and insides were predicted by taxonomic relatedness alone. In contrast, by age 8, inferences about both disease and insides

were predicted by ecological relatedness alone. Finally, among rural 10-year-olds, we see precisely the same pattern observed among undergraduates; both taxonomic and ecological relatedness predicted reasoning about insides, whereas ecological relatedness alone predicted reasoning about disease. In sum, rural children showed a strong pattern of selective induction from early on; consequently, developmental change centered around what relations predicted their inferences.

Urban children: In marked contrast to rural children, urban children showed the weakest pattern of inductive selectivity. As noted earlier, although the relative frequency of ecological inferences was higher among urban 8- and 10-year-olds' reasoning about disease than among those reasoning about insides, urban 6-year-olds showed no such differences (see Figure 2). Likewise, urban children showed a reliable preference for taxonomic inferences about insides at age 8, $t(22) = 3.29$, $p = .003$, $d = 1.40$, and for ecological inferences about disease at age 10, $t(17) = 3.58$, $p = .002$, $d = 1.74$, but no reliable preferences at age 6.

Examination of consistent response patterns supports this picture of later emerging selectivity (see Table 4). Among 6-year-olds, the distribution of response patterns did not differ by property, $\chi^2(2, n = 43) = 2.40$, $p = .302$. For 8-year-olds, response patterns varied marginally by property, $\chi^2(2, n = 41) = 4.75$, $p = .093$; consistent taxonomic patterns were frequent for *insides* and rare for *disease*, whereas consistent taxonomic patterns did not vary by property. Even by age 10, although the property effect was reliable, $\chi^2(2, n = 34) = 6.88$, $p = .032$, the distributions still varied only for consistent taxonomic patterns.

Among urban children, premise–target relations were only very weakly related to inference frequency at ages 6 and 8 (see Table 5). Specifically, at age 6, ecological inferences about disease were marginally predicted by ecological relatedness, and at age 8, they were marginally predicted by taxonomic relatedness, although in both cases the overall regression equations did not reach significance ($p > .10$). By age 10, however, inferences about disease and insides were predicted by different kinds of knowledge; taxonomic relatedness predicted inferences about insides, whereas ecological relatedness predicted inferences about disease. In sum, relative to rural children, selective induction emerged later among urban children, and evidence for selectivity was weaker in every age group.

Suburban children: These children showed an intermediate pattern; selective induction was evident

earlier than among urban children, but was somewhat weaker and less consistent than among rural children. Like rural children, the relative frequency of ecological inferences was higher among suburban children's reasoning about disease than among those reasoning about insides at all ages (see Figure 2). Like urban children, suburban children showed a reliable preference for taxonomic inferences about insides at age 8, $t(23) = 3.70$, $p = .001$, $d = 1.54$, and for ecological inferences about disease at age 10, $t(16) = 4.13$, $p = .001$, $d = 2.07$. Unlike urban children, suburban 6-year-olds showed a reliable preference for ecological inferences about disease, $t(20) = 2.74$, $p = .013$, $d = 1.23$.

Suburban children's consistent response patterns also revealed an intermediate pattern of selectivity (see Table 4). For 6-year-olds, like their urban counterparts, consistent response patterns did not differ by property, $\chi^2(2, n = 39) = 4.08$, $p = .130$. For 8-year-olds, consistent ecological patterns were frequent for *disease* and rare for *insides*, but consistent taxonomic patterns did not vary reliably with property, $\chi^2(2, n = 46) = 6.22$, $p = .045$. It was not until age 10 that suburban children showed the same pattern seen for adults and for rural children at all ages in which consistent ecological patterns were frequent for *disease* and rare for *insides*, and consistent taxonomic patterns were frequent for *insides* and rare for *disease*, $\chi^2(2, n = 32) = 8.41$, $p = .015$.

For suburban 6-year-olds, premise–target relations did not predict inferences. For suburban 8-year-olds—like rural 6-year-olds—inferences about disease and insides were both predicted by taxonomic relatedness alone. However, by age 10, suburban children's inferences about disease and insides were predicted by different relations; taxonomic relatedness predicted reasoning about insides, whereas ecological relatedness predicted reasoning about disease (see Table 5). In sum, selectivity was evident earlier among suburban than urban children, but was weaker than among rural children of the same age until age 10.

Discussion

This study had two major goals. The first was to investigate the development of children's category-based ecological reasoning—that is, their willingness to project a novel property from one species to a dissimilar but ecologically related species—and the degree to which differences in environment and relevant experience among children led to differences in

such reasoning. The second was to explore the development of selective ecological reasoning—children's ability to draw different inferences about different properties—and environmental differences in the development thereof.

Environment, Experience, and Ecological Reasoning

Results showed that children were certainly willing to project novel properties from one species to a dissimilar but ecologically related species, and to do so systematically. At the very least, this indicates that the knowledge underlying children's inductive inferences is not limited to similarity or category membership. Children use other contextual or causal relations—in this case, shared habitat, or food chains—to guide the projection of novel properties, and indeed, do so increasingly with development.

Results also reveal clear effects of both domain-relevant experience and environment on ecological reasoning. Relevant experience influenced reasoning; the extent to which children reported engaging in activities related to "exploring nature" predicted the frequency of ecological inferences. Notably, of the wide range of activities captured in children's self-reports and reflected in the factor analysis, the only activity directly related to ecological reasoning involved informal, unsupervised exploration of nature. Indeed, informal exploration played more of a role in predicting ecological reasoning than more formally structured experiences like zoos or aquariums, or potentially more direct and hands-on experiences like house pets and gardening. This is not to imply that such experiences are not valuable, or do not contribute to children's biological reasoning; there is good evidence that they do (e.g., Inagaki, 1990). However, it does suggest that something about informal, unstructured exploration supports attention to nontaxonomic (and perhaps less perceptually obvious) relations among species, which in turn support ecological inferences. Perhaps "exploring nature" is especially germane to ecological reasoning because it allows children to encounter plants and animals as part of an ecosystem, rather than in isolation as they are often presented in zoos and aquariums. Regardless of the specific mechanism, however, this relation underscores the large potential value and impact of informal, unstructured exploration on children's understanding of the world more generally.

Strikingly, simply living in a less densely populated environment promoted ecological reasoning above and beyond the effects of specific reported

experiences. Presumably, rural environments afford children a greater potential to observe and interact with species in relatively intact ecosystems. If so, the environmental effect suggests that ecological reasoning may not be a special case of expert reasoning but rather a natural and powerful type of induction (see Coley & Vasilyeva, 2010) that develops in part from mere exposure to a sufficiently rich biological environment—precisely the kind of environment in which our hominid ancestors lived. This raises the provocative question of whether the development of ecological reasoning among rural children in this study was accelerated, or whether the development of suburban and urban children's ecological reasoning was delayed (see Medin et al., 2010; Ross et al., 2003, for further consideration of this issue). At this point, these questions and suggestions are merely speculative, but they cry out for further empirical exploration.

Development of Selective Ecological Reasoning

A second goal of the study was to explore the development of selective ecological reasoning. Data from undergraduates provide a snapshot of selectivity in nonexpert adult folk biological reasoning. When reasoning about insides, undergraduates preferred taxonomic inferences and when reasoning about disease, they preferred ecological inferences. Consistent ecological responders were more common for *disease*, and consistent taxonomic responders were more common for *insides*. Undergraduates also selectively attended to premise–target relations; both taxonomic and ecological relatedness influenced inferences about insides, but only ecological relatedness influenced inferences about disease. In sum, undergraduates selectively drew inferences based on both taxonomic and ecological relations among species as a function of the property being projected. These findings replicate previous demonstrations of adults' selective induction in folk biology (e.g., Coley & Vasilyeva, 2010; Heit & Rubinstein, 1994) and also emphasize the sophisticated nature of even novice folk biological reasoning; undergraduates presented with the same species not only drew different inferences about novel diseases versus insides, but also attended to different relations among species when doing so.

Incredibly, this sophisticated pattern of selective reasoning was also clearly evident among 10-year-old children. Ten-year-olds drew more ecological inferences about disease than insides (and indeed showed a consistent preference for ecological inferences about disease). Ten-year-olds' consistent

response patterns were distributed differently for *disease* versus *insides*, with more children consistently drawing taxonomic inferences about insides, and more children consistently drawing ecological inferences about disease (except among urban children). Perhaps most strikingly, different premise–target relations predicted inferences in the two property conditions. Children reasoning about insides attended to taxonomic relatedness among species, whereas children reasoning about disease attended to ecological relatedness. Thus, 10-year-olds' inferences were selective in sophisticated ways; when reasoning about disease, not only did they prefer inferences to ecologically related species, but also in making those inferences they selectively attended to ecological relations between premise and target species. In contrast, when reasoning about insides, they were much less likely to make ecological inferences, and they selectively attended to taxonomic relations between premise and target species.

Results also demonstrate environmental differences in the development of selective folk biological reasoning. First, selectivity appeared earlier among rural children; rural 6-year-olds made more ecological inferences for disease than for insides, consistent response patterns showed the same property-dependent distribution as adults, and although inferences were not differentially related to relational salience, they were systematically predicted by taxonomic relatedness in both conditions. In contrast, although suburban 6-year-olds made more ecological inferences for disease than for insides, urban 6-year-olds did not, and neither group showed property-dependent distributions of consistent response patterns or any systematic relations between premise–target relatedness and inferences. At age 6, then, selectivity was clearly evident among rural children, but only marginally present among suburban children and completely absent among urban children.

Second, adult patterns of selectivity were evident earlier (or only) among rural children. For consistent response patterns, rural children showed adult-like selectivity (distributions of consistent taxonomic and ecological patterns both varied by property) at age 6, whereas suburban children did not show this adult pattern until age 10 and urban 10-year-olds—although they showed some differentiation—still failed to match adults qualitatively. And although all three groups of 10-year-olds attended to different relations when reasoning about insides versus disease, only rural 10-year-olds showed the same qualitative pattern as adults; they were the only group of children to simultaneously

consider both taxonomic and ecological relatedness when reasoning about insides. Indeed, the performance of rural 10-year-olds was virtually indistinguishable from that of undergraduates.

In sum, sophisticated selective inferences were evident by age 10 in all populations, suggesting that different kinds of environment and domain-relevant experience can eventually lead to similar conceptual outcomes. However, for rural children, these patterns emerged earlier and more closely resembled adult performance, showing an important effect of environment on developmental trajectory. Finally, it is important to emphasize that these results should not be taken to indicate any global differences between rural and urban children with respect to conceptual sophistication. The evidence presented here about differences between rural and urban children in the development of selective induction is specific to biological reasoning. I have argued that rural children's advantage in folk biology stems from their richer experience in that domain. Indeed, it would be interesting to find a contrasting domain in which urban children have richer relevant experience to see whether the pattern of differences is reversed. Although I would predict that any systematic difference in domain-relevant experience would lead to analogous differences in reasoning, this demonstration must await future research.

What Drives Environmental Differences?

The environmental and experiential differences documented here demonstrate clear developmental continuity in the way in which contextual factors influence reasoning. Children with richer domain-relevant experience were more likely to draw ecological inferences, and more likely to do so selectively; this closely parallels the adult literature on expertise and inductive reasoning that documents knowledge-related increases in nontaxonomic reasoning (e.g., Coley et al., 2005; López et al., 1997; Proffitt et al., 2000) and selectivity (Shafto & Coley, 2003). Indeed, the present results extend that literature by demonstrating a quantitative relation between differences in environment and relevant experience and differences in ecological reasoning. Thus, domain-relevant experience seems to have precisely the same cognitive effects on children that it has on adults.

One important question raised by these results concerns the mechanism by which environment and relevant experience lead to differences in ecological reasoning. In most cases, taxonomic relations are predictable from perceptual cues; in contrast, ecological relations such as shared habitat or predation typically are not. Therefore, ecological inferences rely on prior knowledge of relations among species in a way that taxonomic inferences do not. In order to draw an ecological inference, one must (a) know that the species in question are related ecologically and (b) believe that the ecological relation is relevant for the projection of the property. According to this analysis, systematic differences in ecological reasoning could arise from differences in *knowledge* of ecological relations, or differences in *beliefs about the relevance* of ecological relations to property projection.

In the first case, children might all have general beliefs about the relevance of ecological relations for guiding inferences, but children from more rural environments, and children who spend time exploring the outdoors, might simply accrue more knowledge about specific ecological relations, and therefore be more familiar with the ecological relations in our stimuli. In other words, the difference in reasoning could be driven by a difference in the extent of children's ecological knowledge base. Alternatively, differences in ecological reason may arise from differential attention to ecological relations and beliefs about their relevance to guiding inferences. Even if children all had equivalent knowledge of ecological *relations*, differences in ecological *reasoning* could arise if rural children considered ecological relations to be relevant bases for property projection in a way that urban children did not. Of course, differences could also arise from an interaction of these factors. To tease apart these possibilities, we would want to know whether the urban and suburban children knew the ecological relations and failed to use them to guide inferences, or just did not know them. The present study does not allow us to answer this question; clearly this is another important avenue for future research.

Conclusions

There are a number of important conclusions to be taken from these findings. First, these results broaden our perspective on category-based induction and put recent debates about the primacy of similarity-based versus category-based induction into a larger context by demonstrating that children have a much richer range of conceptual relations available to them than just ''categories'' and ''similarity,'' that they use such relations to guide inferences increasingly with development, and that they selectively utilize these relations to guide inferences in a sophisticated and context-sensitive

manner. Second, these results demonstrate how extrinsic influences like environment and domain-relevant experience can influence the development of a basic conceptual process like inductive inference. This was evident in at least two ways: Relevant experience and rural environment were associated with an increase in children's ecological reasoning, and rural children demonstrated adult-like selectivity earlier than suburban and urban children. This variability would be invisible without looking at how development unfolds in different contexts, emphasizing the importance of a comparative perspective (e.g., Coley, 2000; Henrich, Heine, & Norenzayan, 2010; Medin et al., 2010). And finally, as researchers increasingly document the positive effects of exposure to nature on both child development and adult cognitive and social functioning (e.g., Faber Taylor & Kuo, 2006; Kahn, 1999; Kaplan, 1995; Kuo, 2003), these results document yet another benefit of informal interaction with nature, namely, the development of more sophisticated and selective biological reasoning.

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Appendix

Complete list of stimuli for triad induction task, including taxonomic relatedness (TR) and ecological relatedness (ER) scores for each triad.

Premise	Taxonomic match	Ecological match	TR score	ER score
Habitat items				
Oak tree	Grass	Squirrel	.75	.47
Cattail	Dandelion	Bullfrog	.74	.44
Water lily	Clover	Heron	.71	.42
Maple	Strawberry plant	Owl	.63	.28
Duck	Eagle	Otter	.65	.33
Pelican	Blue jay	Humpback whale	.79	.36
Pond turtle	Garter snake	Beaver	.33	.22
Squirrel	Groundhog	Robin	.62	.15
Cactus	Bamboo	Armadillo	.61	.75
Giant sea kelp	Palm tree	Hammerhead shark	.53	.81
Jungle vines	Algae	Parrot	.50	.47
Air plant	Aloe plant	Tree frog	.80	.36
Crocodile	Emerald tree boa	Elephant	.71	.22
Flamingo	Emu	Hippopotamus	.63	.69
Jaguar	Kangaroo	Macaw	.58	.32
Hyena	Musk ox	Ostrich	.63	.06
Predation items				
Honeysuckle	Fern	Hummingbird	.69	.78
Pine tree	Buttercup	Termite	.68	.86
Milkweed	Birch	Butterfly	.63	.52
Sunflower	Moss	Bee	.46	.66
Chipmunk	Seal	Hawk	.13	.83
Salmon	Swordfish	Bear	.86	.61
Mosquito	Dragonfly	Bat	.69	.17
Field mouse	Moose	Snake	.50	.75
Savannah grass	Redwood	Zebra	.69	.89
Banana tree	Calla lily	Monkey	.61	.80
Eucalyptus	Orchid	Koala	.72	.80
Prairie grass	Venus fly trap	Buffalo	.63	.67
Herring	Clownfish	Penguin	.69	.69
Leafcutter ant	Scorpion	Anteater	.69	.39
Lemming	Wombat	Snowy owl	.75	.44
Antelope	Panda	Vulture	.65	.72