Folk Biology and the Anthropology of Science: Cognitive Universals and Cultural Particulars

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Abstract

This essay in the "anthropology of science" is about how cognition constrains culture in producing science. The example is folk biology, whose cultural recurrence issues from the very same domain-specific cognitive universals that provide the historical backbone of systematic biology. Humans everywhere think about plants and animals in highly structured ways. People have similar folk-biological taxonomies composed of essence-based species-like groups and the ranking of species into lower- and higher-order groups. Such taxonomies are not as arbitrary in structure and content, nor as variable across cultures, as the assembly of entities into cosmologies, materials or social groups. These structures are routine products of our "habits of mind," which may be in part naturally selected to grasp relevant and recurrent "habits of the world." An experiment illustrates that the same taxonomic rank is preferred for making biological inferences in two diverse populations: Lowland Maya and Midwest Americans. These findings cannot be explained by domain-general models of similarity because such models cannot account for why both cultures prefer species-like groups, despite the fact that Americans have relatively little actual knowledge or experience at this level. This supports a modular view of folk biology as a core domain of human knowledge and as a special player, or "core meme," in the selection processes by which cultures evolve. Structural aspects of folk taxonomy provide people in different cultures with the built-in constraints and flexibility that allow them to understand and respond appropriately to different cultural and ecological settings. Another set of reasoning experiments shows that the Maya, American folk and scientists use similarly structured taxonomies in somewhat different ways to extend their understanding of the world in the face of uncertainty. Although folk and scientific taxonomies diverge historically, they continue to interact. The theory of evolution may ultimately dispense with the core concepts of folk biology, including species, taxonomy and teleology; in practice, however, these may remain indispensable for scientific work. Moreover, theory-driven scientific knowledge cannot simply replace folk knowledge in everyday life. Folk-biological knowledge is not

driven by implicit or inchoate theories of the sort science aims to make more accurate and perfect.

INTRODUCTION [1]

In every human society, people think about plants and animals in the same special ways. These special ways of thinking, which can be described as "folk biology," are fundamentally different from the ways humans ordinarily think about other things in the world, such as stones, stars, tools or even people. The science of biology also treats plants and animals as special kinds of objects, but applies this treatment to humans as well. Folk biology, which is present in all cultures, and the science of biology, whose origins are particular to Western cultural tradition, have corresponding notions of living kinds.

Consider four corresponding ways in which ordinary folk and biologists think of plants and animals as special. First, people in all cultures classify plants and animals into species-like groups that biologists generally recognize as populations of interbreeding individuals adapted to an ecological niche. We will call such groups - such as redwood, rye, raccoon or robin - "generic species" for reasons that will become evident. Generic species are usually as obvious to a modern scientist as to local folk. Historically, the generic-species concept provided a pretheoretical basis for scientific explanation of the organic world in that different theories - including evolutionary theory - have sought to account for the apparent constancy of "common species" and for the organic processes that center on them (Wallace 1889/1901:1)

Second, there is a commonsense assumption that each generic species has an underlying causal nature, or essence, which is uniquely responsible for the typical appearance, behavior and ecological preferences of the kind. People in diverse cultures consider this essence responsible for the organism's identity as a complex, self-preserving entity governed by dynamic internal processes that are lawful even when hidden. This hidden essence maintains the organism's integrity even as it causes the organism to grow, change form and reproduce. For example, a tadpole and frog are in a crucial sense the same animal although they look and behave very differently, and live in different places. Western philosophers, such as Aristotle and Locke, attempted to translate this commonsense notion of essence into some sort of metaphysical reality, but evolutionary biologists reject the notion of essence as such. Nevertheless, biologists have traditionally interpreted this conservation of identity under change as due to the fact that organisms have separate genotypes and phenotypes.

Third, in addition to the spontaneous division of local flora and fauna into essence-based species, such groups have "from the remotest period in... history... been classed in groups under groups. This classification [of generic species into higher- and lower-order groups] is not arbitrary like the grouping of stars in constellations" (Darwin 1872/1883:363).[2] The structure of these hierarchically included groups, such as white oak/oak/tree or mountain robin/robin/bird, is referred to as "folk-biological taxonomy." Especially in the case of animals, these nonoverlapping taxonomic structures can often be scientifically interpreted in terms of speciation (that is, related species descended from a common ancestor by splitting off from a lineage).

Fourth, such taxonomies not only organize and summarize biological information; they also provide a powerful inductive framework for making systematic inferences about the likely distribution of organic and ecological properties among organisms. For example, given the presence of a disease in robins one is "automatically" justified in thinking that the disease is more likely to present among other bird species than among nonbird species. In scientific taxonomy, which belongs to the branch of biology known as systematics, this strategy receives its strongest expression in "the fundamental principle of systematic induction" (Warburton 1967, Bock 1973). On this principle, given a property found among members of any two species, the best initial hypothesis is that the property is also present among all species that are included in the smallest higher-order taxon containing the original pair of species. For example, finding that the bacteria E-scheriehia coli share a hitherto unknown property with robins, a biologist would be justified in testing the hypothesis that all organisms share the property. This is because E. coli link up with robins only at the highest level of taxonomy, which includes all organisms.

As we shall see, these four corresponding notions issue from a specific cognitive structure, which may be a faculty of the human mind that is innately and uniquely attuned to perceiving and conceptually organizing living kinds. The evolutionary origins of such a faculty arguably involved selection pressures bearing on immediate utility, such as obtaining food and surviving predators and toxins. In no society, however, do people exclusively classify plants and animals because they are useful or harmful. This claim goes against the generally received view that folk biologies are primarily utilitarian, and that scientific biology emerged in part to expel this utilitarian bias from systematic thinking about the living world. Rather, the special ways people classify organic nature enable them to systematically relate fairly well-delimited groups of plants and animals to one another in indefinitely many ways, and to make reasonable predictions about how biological properties are distributed among these groups, regardless of whether or not those properties are noxious or beneficial.

Although folk biology and the science of biology share a psychological structure, they apply somewhat different criteria of relevance in constructing and interpreting notions of species, underlying causal structure, taxonomy and taxonomy-based inference. Given the universal character of folk biology, a plausible speculation is that it evolved to provide a generalized framework for understanding and appropriately responding to important and recurrent features in hominid ancestral environments. By contrast, the science of biology has developed to understand an organization of life in which humans play only an incidental role no different from other species.Thus, although there are striking similarities between folk taxonomies and scientific taxonomies, we will also find that there are radical differences. To explore how these different criteria of relevance function, the folk-biological taxonomies of American students and Maya Indians are compared and contrasted below with scientific taxonomies.

In this target article, we first describe universal aspects of folk biology. We then show where and why folk biology and scientific biology converge and diverge. In the final part, we explain how folk biology and scientific biology continue to interact in the face of the historical differences that have emerged between them. The focus is on taxonomy and taxonomy-based inference. The general approach belongs to "the anthropology of science," which this paper illustrates. The examples of biology do not apply straightaway to all of science, any more than those of systematics apply to all of biology, but they are central enough in the history of science to be a good place to begin.

1.Folk-Biological Taxonomy.

Over a century of ethnobiological research has shown that even within a single culture there may be several different sorts of "special-purpose" folk-biological classifications that are organized by particular interests for particular uses (e.g., beneficial versus noxious, domestic versus wild, edible versus inedible, etc.). Only in the last decades has intensive empirical and theoretical work revealed a cross-culturally universal "general-purpose" taxonomy (Berlin, Breedlove & Raven 1973) that supports systematic reasoning about living kinds, and properties of living kinds, in the face of uncertainty (Atran 1990). For example, learning that one cow is susceptible to "mad cow" disease one might reasonably infer that all cows are susceptible to the disease but not that all mammals or animals are.

This "default" folk-biological taxonomy, which serves as an inductive compendium of biological information, is composed of a fairly rigid hierarchy of inclusive groups of organisms, or taxa. At each level of the hierarchy, the taxa, which are mutually exclusive, partition the locally perceived biota in a virtually exhaustive manner. Lay taxonomy, it appears, is everywhere composed of a small number of absolutely distinct hierarchical levels, or ranks. Anthropologist Brent Berlin (1992) has established the standard terminology for folk-biological ranks as follows: the "folk-kingdom" rank (e.g., animal, plant), the "life-form" rank (e.g., bug, fish, bird, mammal, tree, herb/grass, bush), the "generic" or "generic-species" rank (e.g., gnat, shark, robin, dog, oak, clover, holly), the "folk-specific" rank (poodle, white oak) and the "folk-varietal" rank (toy poodle; spotted white oak). Taxa of the same rank tend to display similar linguistic, biological and psychological characteristics.

1.1. The Significance of Rank.

Rank allows generalizations to be made across classes of taxa at any given level. For example, the living members of a taxon at the generic-species level generally share a set of biologically important features that are functionally stable and interdependent (homeostasis); members can generally interbreed with one another but not with the living members of any other taxon at that level (reproductive isolation). Taxa at the life-form level generally exhibit the broadest fit (adaptive radiation) of morphology (e.g., skin covering) and behavior (e.g., locomotion) to habitat (e.g., air, land, water). Taxa at the subordinate folk-specific and folk-varietal levels often reflect systematic attempts to demarcate biological boundaries through cultural preferences. .

The generalizations that hold across taxa of the same rank (i.e., a class of taxa) thus differ in logical type from generalizations that apply only to this or that taxon (i.e, a group of organisms). Termite, pig and lemon tree are not related to one another by virtue of any simple relation of class inclusion or connection to some common hierarchical node, but by dint of their common rank - in this case the level of generic species. Notice that a system of rank is not simply a hierarchy, as some suggest (Rosch 1975, Premack 1995, Carey 1996). Hierarchy, that is, a structure of inclusive classes, is common to many cognitive domains, including the domain of artifacts. For example, chair often falls under furniture but not vehicle, and car falls under vehicle but not furniture. But there is no ranked system of artifacts:[3] no inferential link, or inductive framework, spans both chair and car, or furniture and vehicle, by dint of a common rank, such as the artifact species or the artifact family. In other words, in many domains there is hierarchy without rank, but only in the domain of living kinds is there always rank.

Ranks and taxa are of a different logical order, and confounding them is a category mistake. Biological ranks are second-order classes of groups (e.g., species, family, kingdom) whose elements are first-order groups (e.g., lion, feline, animal). Ranks seem to vary little, if at all, across cultures as a function of theories or belief systems. In other words, ranks are universal but not the taxa they contain. Ranks represent fundamentally different levels of reality, not convenience. Consider:

The most general rank is the folk kingdom,[4] that is, plant or animal. Such taxa are not always explicitly named but they represent the most fundamental divisions of the biological world. These divisions correspond to the notion of "ontological category" in philosophy (Donnellan 1971) and psychology (Keil 1979). From an early age humans cannot help but conceive of any object they see in the world as either being or not being an animal, and there is evidence for an early distinction between plants and nonliving things (Gelman & Wellman 1991, Keil 1994, Hickling & Gelman 1995, Hatano & Inagaki 1996). Conceiving of an object as a plant or animal seems to carry certain assumptions that are not applied to objects thought of as belonging to other ontological categories, like person, substance or artifact.

The next rank down is that of life form.[5] The majority of taxa of lesser rank fall under one or another life form. Most life-form taxa are named by lexically unanalyzable names (primary lexemes), and have further named subdivisions, such as tree and bird. Biologically, members of a single life-form taxon are diverse. Psychologically, members of a life-form taxon share a small number of perceptual diagnostics, such as stem aspect, skin covering and so forth (Brown 1984). Life-form taxa may represent general adaptations to broad sets of ecological conditions, such as competition among single-stem plants for sunlight and tetrapod adaptation to life in the air (Hunn 1982, Atran 1985a). Classification by life form may occur relatively early in childhood. For example, familiar kinds of quadrupeds (e.g., dogs and horses) are classified separately from sea versus air animals (Mandler, Bauer & McDonough 1991; Dougherty 1979 for American plants; Stross 1973 for Maya).

The core of any folk taxonomy is rank of generic species, which contains by far the most numerous taxa in any folk-biological system. Taxa of this rank generally fall under some life form, but there may be outliers that are unaffiliated with any major life-form taxon.[6] This is often so for a plant or an animal of particular cultural interest, such as maize for Maya (Berlin, Breedlove & Raven 1974) and the cassowary for the Karam of New Guinea (Bulmer 1970). Like life-form taxa, generic-species taxa are usually named by primary lexemes, such as oak and robin. Occasionally, generic-species names exhibit variant forms of what systematists refer to as binomial nomenclature: for example, binomial compounds, such as hummingbird, or binomial composites, such as oak tree. In both these cases the binomial makes the hierarchical relation apparent between the generic species and the life form.

Generic species often correspond to scientific genera or species, at least for those organisms that humans most readily perceive, such as large vertebrates and flowering plants. On occasion, generic species correspond to local fragments of biological families (e.g., vulture), orders (e.g., bat) and, especially with invertebrates, even higher-order taxa (Atran 1987a, Berlin 1992). Generic species also tend to be the categories most easily recognized, most commonly named and most readily learned in small-scale societies (Stross 1973).

Generic species may be further divided at the folk-specific level. Folk-specific taxa are usually labeled binomially, with secondary lexemes. Such compound names make transparent the hierarchical relation between a generic species and its subordinate taxa, like white oak and mountain robin. However, folk-specific taxa that belong to a generic species with a long tradition of high cultural salience may be labeled with primary lexemes, like winesap (a kind of apple tree) and tabby (a kind of cat). Partitioning into subordinate taxa usually occurs as a set of two or more taxa that contrast lexically along some readily perceptible dimension (color, size, etc.); however, such contrast sets often involve cultural distinctions that language and perception alone do not suffice to explain (Hunn 1982). An example is the Itzaj Maya contrast between red mahogany (ch%k ch%k-al~te') and white mahogany (s%k ch%k-al~te'). Red mahogany actually appears to be no redder than white mahogany. Rather, red mahogany is preferred for its beauty because it has a deeper grain than white mahogany. It is "red" as opposed to "white" probably because Lowland Maya traditionally associate red with the true wind of the East, which brings rain and bounty, and white with the false wind of the North, which brings deception (Atran in press).

In general, whether or not a generic species is further differentiated depends on cultural importance. Occasionally, an important folk-specific taxon will be further subdivided into contrasting folk-varietal taxa, such as short-haired tabby and long-haired tabby. Varietals are usually labeled trinomially, with tertiary lexemes that make transparent their taxonomic relationship with superordinate folk-specifics and generic species. An example is spotted white oak.

Foreign organisms introduced into a local environment are often initially assimilated to generic species through folk-specific taxa. For example, European colonists originally referred to New World maize as "Indian corn," that is, a kind of wheat. Similarly, Maya initially dubbed Old World wheat "Castillian maize." Over time, as the introduced species acquired its own distinctive role in the local environment, it would assume generic-species status and would, as with most other generic species, be labeled by a single lexeme (e.g., "corn" in American English now refers exclusively to maize).

Finally, intermediate levels also exist between the generic-species and life-form levels. Taxa at these levels usually have no explicit name (e.g., rats + mice but no other rodents), although they sometimes do (e.g., felines, palms). Such taxa - especially unnamed "covert" ones - tend not to be as clearly delimited as generic species or life forms; nor does any one intermediate level always constitute a fixed taxonomic rank that partitions the local fauna and flora into a mutually exclusive and virtually exhaustive set of broadly equivalent taxa. Still, there is a psychologically evident preference for forming intermediate taxa at a level roughly between the scientific family (e.g., canine, weaver bird) and order (e.g., carnivore, passerine) (Atran 1983, Berlin 1992).

1.2. The Generic Species: Principal Focus of Biological Knowledge.

People in all cultures spontaneously partition the ontological categories animal and plant into generic species in a virtually exhaustive manner. "Virtually exhaustive" means that when an organism is encountered that is not readily identifiable as belonging to a named generic species, it is still expected to belong to one. The organism is usually assimilated to one of the named taxa it resembles, although at times it is assigned an "empty" generic-species slot pending further scrutiny (e.g., "such-and-such a plant is some [generic-species] kind of tree," see Berlin in press). This partitioning of ontological categories seems to be part and parcel of the categories themselves: no plant or animal can fail to belong uniquely to a generic species.

The term "generic species" is used here, rather than "folk genera/folk generic" (Berlin 1972) or "folk species/folk specieme" (Bulmer 1970), for three reasons:[7] (1) a principled distinction between biological genus and species is not pertinent to most people around the world. For humans, the most phenomenally salient species (including most species of large vertebrates, trees, and phylogenetically isolated groups such as palms and cacti) belong to monospecific genera in any given locale.[8] Closely related species of a polytypic genus are often hard to distinguish locally, and no readily perceptible morphological or ecological "gap" can be discerned between them (Diver 1940).

(2) The term "generic species" reflects a more accurate sense of the correspondence between the most psychologically salient folk-biological groups and the most historically salient scientific groups (Stevens 1994). The distinction between genus and species did not appear until the influx of newly discovered species from around the world compelled European naturalists to sort and remember them within a worldwide system of genera built around (mainly European) species types (Atran 1987a).

(3) The term "generic species" reflects a dual character. As salient mnemonic groups, they are akin to genera in being those groups most readily apparent to the naked eye (Cain 1956). As salient causal groups, they are akin to species in being the principal centers of evolutionary processes responsible for biological diversity (Mayr 1969).

1.2.1. The Evolutionary Sense of an Essence Concept.

From the standpoint of hominid evolution, the concept of such an essential kind may represent a balancing act between what our ancestors could and could not afford to ignore about their environment. The concept of generic species allows people to perceive and predict many important properties that link together the members of a biological species actually living together at any one time, and to distinguish such species from one another. By contrast, the ability to appreciate the graded phylogenetic relationships between scientific species, which involve vast expanses of geological time and geographical space, would be largely irrelevant to the natural selection pressures on hominid cognition.

Ernst Mayr (1969) calls such "local" species, which are readily observed over one or a few generations to coexist in a given local environment, "non-dimensional species" for two reasons: they are manifest to the untrained eye, with no need for theoretical reflection; and the perceptible morphological, ecological and reproductive gaps separating such species summarize the evolutionary barriers between them. Mayr argues that the awareness of non-dimensional species provides the necessary condition for further insight and exploration into phylogenetic species; any sufficient condition for scientific understanding, however, must go beyond essentialism.

People ordinarily assume that the various members of each generic species share a unique underlying nature, or essence. This assumption carries the inference of a strong causal connection between superficially dissimilar or noncontiguous states or events - an inference that other animals or primates do not seem capable of making (cf. Kummer 1994). People reason that even three-legged, purring, albino tiger cubs are by nature large, striped, roaring, carnivorous quadrupeds. This is because there is presumably something "in" tigers that is the common cause of them growing large, having stripes, eating meat and roaring under "normal" conditions of existence. People expect the disparate properties of a species to be integrally linked without having to know precise causal relationships.

A biological essence is an intrinsic (i.e., nonartifactual) teleological agent, which physically (i.e., nonintentionally) causes the biologically relevant parts and properties of a generic species to function and cohere "for the sake of" the generic species itself. For example, even preschoolers in our culture consistently judge that the thorns on a rose bush exist for the sake of there being more roses, whereas physically similar depictions of barbs on barbed wire or the protuberances of a jagged rock are not considered to exist for the sake of there being more barbed wire or jagged rocks (Keil 1994).

This concept of underlying essence goes against the claim that "biological essentialism is the theoretical elaboration of the logical-linguistic concept, substance sortal" that applies to every count noun (Carey 1996:194). Chair may be defined in terms of the human function it serves, and mud in terms of its physical properties, but neither have deep essences because neither is necessarily assumed to be the unique outcome of an imperceptible causal complex. For example, a three-legged or legless beanbag chair does not lack "its" legs, because although most chairs "normally" have four legs they are not quadrupedal by nature (cf. Schwartz 1978). Neither is the notion of essence merely that of a common physical property. Red things comprise a superficial natural class, but such things have little in common except that they are red; and they presumably have few, if any, features that follow from this fact.

People the world over assume that the initially imperceptible essential properties of a generic species are responsible for the surface similarities they perceive. People strive to know these deeper properties but also assume that the nature of a species may never be known in its entirety. This cognitive compulsion to explore the underlying nature of generic species produces a continuing and perhaps endless quest to better understand the surrounding natural world, even though such understanding seldom becomes globally coherent or consistent.

1.2.2. A Taxonomic Experiment on Rank and Preference.

Given these observations, cognitive studies of the "basic level" are at first sight striking and puzzling. In a justly celebrated set of experiments, Rosch and her colleagues set out to test the validity of the notion of a psychologically preferred taxonomic level (Rosch, Mervis, Grey, Johnson & Boyes-Braem 1976). Using a broad array of converging measures, they found that there is indeed a "basic level" in category hierarchies of "naturally occurring objects," such as "taxonomies" of artifacts as well as living kinds. For artifact and living kind hierarchies, the basic level is where: (1) many common features are listed for categories, (2) consistent motor programs are used for the interaction with or manipulation of category exemplars, (3) category members have similar enough shapes so that it is possible to recognize an average shape for objects of the category, (4) the category name is the first one to come to mind in the presence of an object (e.g., "table" versus "furniture" or "kitchen table").

There is a problem, however: The basic level that Rosch et al. (1976) had hypothesized for artifacts was confirmed (e.g., hammer, guitar); however, the hypothesized basic level for living kinds (e.g., maple, trout), which Rosch initially presumed would accord with the generic-species level, was not. For example, instead of maple and trout, Rosch et al. found that tree and fish operated as basic-level categories for American college students. Thus, Rosch's basic level for living kinds generally corresponds to the life-form level, which is superordinate to the generic-species level (cf. Zubin & Köpcke 1986 for findings with German).

To explore this apparent discrepancy between preferred taxonomic levels in small-scale and industrialized societies, and the cognitive nature of ethnobiological ranks in general, we use inductive inference. Although a number of converging measures have been used to explore the notion of basic levels, there has been little direct examination of the relationship between inductive inference and basic levels. This is all the more surprising in view of the fact that a number of psychologists and philosophers assume that basic-level categories maximize inductive potential as intuitive "natural kinds" which "scientific displines evolve to study" (Carey 1985:171; cf. Gelman 1988, Millikan in press). Inference studies allow us to directly test whether or not there is a psychologically preferred rank that maximizes the strength of any potential induction about biologically relevant information, and whether or not this preferred rank is the same across cultures. If a preferred level carries the most information about the world, then categories at that level should favor a wide range of inferences about what is common among members (cf. Anderson 1990).

The prediction is that inferences to a preferred category (e.g., white oak to oak, tabby to cat) should be much stronger than inferences to a superordinate category (oak to tree, cat to mammal). Moreover, inferences to a subordinate category (spotted white oak to white oak, short-haired tabby to tabby) should not be much stronger than or different from inferences to a preferred category. What follows is a summary of results from one representative set of experiments in two very diverse populations: Midwestern Americans and Lowland Maya (for complete results see Atran, Estin, Coley & Medin in press; Coley, Medin & Atran in press).

1.2.2.1. Subjects and Methods.

The Itzaj are Maya Amerindians living in the Petèn rainforest region of Guatemala. Until recently, men devoted their time to shifting agriculture, hunting and silviculture, whereas women concentrated on the myriad tasks of household maintenance. The Itzaj comprised the last independent native polity to be conquered by Spaniards (in 1697) and they have preserved virtually all ethnobiological knowledge recorded for Lowland Maya since the time of the initial Spanish conquest (Atran 1993). Despite the current awesome rate of deforestation and the decline of Itzaj culture, the language and ethic of traditional Maya silviculture is still very much in evidence among the generation of our informants who range in age from 50 to 80 years old . The Americans were self-identified as people raised in Michigan and recruited through an advertisement in a local newspaper.

Based on extensive fieldwork with the Itzaj, we chose a set of Itzaj folk-biological categories of the kingdom (K), life-form (L), generic-species (G), folk-specific (S), and folk-varietal (V) ranks. We selected three plant life forms: che' = tree, ak' = vine, pok~che' = herb/bush. We also selected three animal life forms: b'a'al~che' kuxi'mal = "walking animal," i.e., mammal, ch'iich' = birds including bats, k%y = fish. Three generic-species taxa were chosen from each life form such that each generic species had a subordinate folk-specific, and each folk-specific had a salient varietal.

Pretesting showed that participants were willing to make inferences about hypothetical diseases. The properties chosen for animals were diseases related to the "heart" (puksik'al), "blood" (k'ik'el), and "liver" (tamen). For plants, diseases related to the "roots" (motz), "sap" (itz) and "leaf" (le'). Properties were chosen according to Itzaj beliefs about the essential, underlying aspects of life's functioning. Thus, the Itzaj word puksik'al, in addition to identifying the biological organ "heart" in animals, also denotes "essence" or "heart" in both animals and plants. The term motz denotes "roots," which is considered the initial locus of the plant puksik'al. The term k'ik'el denotes "blood" and is conceived as the principal vehicle for conveying life from the puksik'al throughout the body. The term itz denotes "sap," which functions as the plant's k'ik'el. The tamen, or "liver," helps to "center" and regulate the animal's puksik'al. The le', or "leaf," is the final locus of the plant puksik'al. Properties used for inferences had the form, "is susceptible to a disease of the <root> called <X>." For each question, "X" was replaced with a phonologically appropriate nonsense name (e.g. "eta") in order to minimize the task's repetitiveness.

All participants responded to a list of over 50 questions in which they were told that all members of a category had a property (the premise) and were asked whether "all," "few," or "no" members of a higher-level category (the conclusion category) also possessed that property. The premise category was at one of four levels, either life-form (e.g. L = bird), generic-species (e.g. G = vulture), folk-specific (e.g. S= black vulture), or varietal (e.g. V = red-headed black vulture). The conclusion category was drawn from a higher-level category, either kingdom (e.g. K = animal), life-form (L), generic-species (G), or folk-specific (S). Thus, there were ten possible combinations of premise and conclusion category levels: L->K, G->K, G->L, S->K, S->L, S->G, V->K, V->L, V->G, and V->S. For example, a folk-specific-to-life form (S->L) question might be, "If all black vultures are susceptible to the blood disease called eta, are all other birds susceptible?" If a participant answers "no," then the follow-up question would be "Are some or a few other birds susceptible to disease eta, or no other birds at all?"

The corresponding life forms for the Americans were: mammal, bird, fish, tree, bush and flower (on flower as an American life form see Dougherty 1979). The properties used in questions for the Michigan participants were "have protein X," "have enzyme Y," and "are susceptible to disease Z." These were chosen to be internal, biologically based properties intrinsic to the kind in question, but abstract enough so that rather than answering what amounted to factual questions participants would be likely to make inductive inferences based on taxonomic category membership.

1.2.2.2. Results.

Representative findings are given in Figure 1. Responses were scored in two ways. First we totaled the proportion of "all or virtually all" responses for each kind of question (e.g., the proportion of times respondents agreed that if red oaks had a property, all or virtually all oaks would have the same property). Second, we calculated "response scores" for each item, counting a response of "all or virtually all" as 3, "some or few" as 2, and "none or virtually none" as 1. A higher score reflected more confidence in the strength of an inference.

Figure 1a summarizes the results from all Itzaj informants for all life forms and diseases, and shows the proportion of "all" responses (black), "few" responses (checkered), and "none" responses (white). For example, given a premise of folk-specific (S) rank (e.g., red squirrel) and a conclusion category of generic-species (G) rank (e.g., squirrel), 49% of responses indicated that "all" squirrels, and not just "some" or "none," would possess a property that red squirrels have. Results were obtained by totaling the proportion of "all or virtually all" responses for each kind of question (e.g., the proportion of times respondents agreed that if red oaks had a property, all or virtually all oaks would have the same property). A higher score represented more confidence in the strength of the inductive inference. Figure 1b summarizes the results of Michigan response scores for all life forms and biological properties.

Response scores were analyzed using t-tests with significance levels adjusted to account for multiple comparisons. Figure 2 summarizes the significant comparisons (p-values) for "all" responses, "none" responses and combined responses. For all comparisons, n = 12 Itzaj participants and n= 21 American participants (for technical details see Atran et al. in press).

Following the main diagonals of Figures 1 and 2 refers to changing the levels of both the premise and conclusion categories while keeping their relative level the same (with the conclusion one level higher than the premise). Induction patterns along the main diagonal indicate a single inductively preferred level. Examining inferences from a given rank to the adjacent higher-order rank (i.e., V->S, S->G, G->L, L->K), we find a sharp decline in strength of inferences to taxa ranked higher than generic species, whereas V->S and S->G inferences are nearly equal and similarly strong. Notice that for "all" responses, the overall Itzaj and Michigan patterns are nearly identical.

Moving horizontally within each graph in Figures 1 and 2 corresponds to holding the premise category constant and varying the level of the conclusion.[9] Here we find the same pattern for "all" responses for both Itzaj and Americans as we did along the main diagonal. However, in the combined response scores ("all" + "few") there is now evidence of increased inductive strength for higher-order taxa among Americans versus Itzaj. On this analysis, both Americans and Itzaj show the largest break between inferences to generic species versus life forms. But only American subjects also show a consistent pattern of rating inferences to life-form taxa higher than to taxa at the level of the folk kingdom: G->K vs. G->L, S->K vs. S->L, and V->K vs. V->L.

Finally, moving both horizontally and along the diagonal, for Itzaj there is some hint of a difference between inductions using conclusions at the generic-species versus folk-specific levels: V->G and S->G are modestly weaker than V->S. Regression analysis reveals that for Itzaj, the folk-specific level accounts for a small proportion of the variance beyond the generic species (1.4%), but a significant one (F > 4). For Michigan participants, the folk-specific level is not differentiated from the generic-species level (0.2, not significant). In fact, most of the difference between V->G and V->S inductions results from inference patterns for the Itzaj tree life form . There is evidence that Itzaj confer some preferential status upon trees at the folk-specific level (e.g. savanna nance tree). Itzaj are forest-dwelling Maya with a long tradition of agroforestry that antedates the Spanish conquest (Atran 1993).

1.2.2.3. Discussion.

These results indicate that both the ecologically inexperienced Americans and the ecologically experienced Itzaj prefer taxa of the generic-species rank in making biological inferences; the findings go against a simple relativist account of cultural differences in folk-biological knowledge. However, the overall effects of cultural experience on folk-biological reasoning are reflected in more subtle ways that do not undermine an absolute preference for the generic species across cultures. In particular, the data point to a relative downgrading of inductive strength to higher ranks among industrialized Americans through knowledge attrition owing to lack of experience and a relative upgrading of inductive strength to lower ranks among silvicultural Maya through expertise.

A secondary reliance on life forms arguably owes to Americans' general lack of actual experience with generic species (Dougherty 1978). In one study, American students used only the name "tree" to refer to 75% of the species they saw in a nature walk (Coley, Medin & Atran in press). Although Americans usually can't tell the difference between beeches and elms, they expect that biological action in the world is at the level of beeches and elms and not tree. Yet without being able at least to recognize a tree, they would not even know where to begin to look for the important biological information. The Itzaj pattern reflects both overall preference for generic species and the secondary importance of lower-level distinctions, at least for kinds of trees. A strong ethic of reciprocity in silviculture still pervades the Itzaj; the Maya tend trees so that the forest will tend to the Maya (Atran & Medin 1997). This seems to translate into an upgrading of biological interest in tree folk-specifics.

These findings cannot be explained by appeals either to cross-domain notions of perceptual "similarity" or to the structure of the world "out there." On the one hand, if inferential potential were a simple function of perceptual similarity then Americans should prefer life forms for induction (in line with Rosch et al.). Yet Americans prefer generic species as do Maya. On the other hand, objective reality - that is, the actual distribution of biological species within groups of evolutionarily related species - does not substantially differ in the natural environments of Midwesterners and Itzaj. Unlike Itzaj, however, Americans perceptually discriminate life forms more readily than generic species. True, there are more locally recognized species of tree in the Maya area of Peten, Guatemala than in the Midwest United States. Still, the readily perceptible evolutionary "gaps" between species are roughly the same in the two environments (most tree genera in both environments are monospecific). If anything, one might expect that having fewer trees in the American environment allows each species to stand out more from the rest (Hunn 1976). For birds the relative distribution of evolutionarily related species also seems to be broadly comparable across temperate and rainforest environments (Boster 1988).

An inadequacy in current accounts of preferred taxonomic levels may be a failure to distinguish domain-general mechanisms for best clustering stimuli from domain-specific mechanisms for best determining loci of biological information. To explain Rosch's data it may be enough to rely on domain-general, similarity-based mechanisms. Such mechanisms may generate a basic level in any number of cognitive domains, but not the preferred level of induction in folk biology.

Perhaps humans are disposed to take tight clusters of covariant perceptual information as strong indicators of a rich underlying structure of biological information. This may be the "default" case for humans under "normal" conditions of learning and exposure to the natural world. By and large, people in small-scale societies would live under such "normal" conditions, involving the same general sorts of ambient circumstances that led to the natural selection of cognitive principles for the domain of folk biology. People in urban societies, however, may no longer live under such "default" conditions (except for hunters, bird watchers etc., Tanaka & Taylor 1991.)

How, then, can people conceive of a given folk-biological category as a generic species without always (or mostly) relying on perception? Ancillary encyclopedic knowledge may be crucial. Thus, one may have detailed knowledge of dogs but not oaks. Yet a story that indicates where an oak lives, or how it looks or grows, or that its life is menaced may be sufficient to trigger the assumption that oaks comprise a generic species just as dogs do. But such cultural learning produces the same results under widely divergent conditions of experience in different social and ecological environments. This indicates that the learning itself is strongly motivated by cross-culturally shared cognitive mechanisms that do not depend primarily on experience.

In conjunction with encyclopedic knowledge of what is already known for the natural world, language is important in targeting preferred kinds. In experiments with children as young as two years old, Gelman and her colleagues showed that sensitivity to nomenclatural patterns and other linguistic cues helps guide folk-biological inferences about information that is not perceptually obvious, especially for categories believed to embody an essence (Gelman, Coley & Gottfried 1994; Hall & Waxman 1993). Language alone, however, is not enough to induce the expectation that little known generic species convey more biological information than better known life forms for Americans. Some other process must invest the generic-species level with inductive potential. Language alone can only signal that such an expectation is appropriate for a given lexical item; it cannot determine the nature of that expectation.

Why assume that an appropriately tagged item is the locus of a "deep" causal nexus of biological properties and relationships? It is logically impossible that such assumptions and expectations come from (repeated exposure to) the stimuli themselves. Input to the mind alone cannot cause an instance of experience (e.g., a sighting in nature or in a picture book), or any finite number of fragmentary instances, to be generalized into a category that subsumes a rich and complex set of indefinitely many instances. This projective capacity for category formation can only come from the mind, not from the world alone.

The empirical question, then, is whether or not this projective capacity of the mind is simply domain-general, or also domain-specific. For any given category domain - say, living kinds as opposed to artifacts or substances - the process would be domain-general if and only if one could generate the categories of any number of domains from the stimuli alone together with the very same cognitive mechanisms for associating and generalizing those stimuli. But current domain-general similarity models of category formation and category-based reasoning fail to account for the generic species as a preferred level for folk-biological taxonomy across cultures.

Our findings suggest that fundamental categorization processes in folk biology are rooted in domain-specific conceptual assumptions rather than in domain-general perceptual heuristics. Subsistence cultures and industrialized cultures may differ in the level at which organisms are most easily identified, but they both still believe that the same absolute level of reality is preferable for biological reasoning, namely, the generic-species rank. This is because they expect the biological world to partition at that rank into nonoverlapping kinds, each with its own unique causal essence, whose visible products may or may not be readily perceived.

People anticipate that the biological information value of these preferred kinds is maximal whether or not there is also a visible indication of maximal covariation of perceptual attributes. This does not mean that more general perceptual cues have no inferential value when applied to the folk-biological domain. On the contrary, the evidence points to a significant role for such cues in targeting basic-level life forms as secondary foci for inferential understanding in a cultural environment where biological awareness is relatively poor, as among many Americans. Possibly there is an evolutionary design to having both domain-general perceptual heuristics and domain-specific learning mechanisms: the one enabling flexible adaptation to the variable conditions of experience; the other more invariable in steering us to those abiding aspects of biological reality that are causally recurrent and especially relevant for the emergence of human life and cognition.

1.3. Evolutionary Ramifications: Folk Biology as a Core Domain of Mind and Culture.

A speculative but plausible claim in light of our observations and findings is that folk biology is a core domain for humans. A core domain is a semantic notion, philosophically akin to Kant's "synthetic a priori." The object domain, which consists of generic species of biological organisms, is the extension of an innate cognitive module. Universal taxonomy is a core module, that is, an innately determined cognitive structure that embodies the naturally selected ontological commitments of human beings and provides a domain-specific mode of causally construing the phenomena in its domain (for a more disembodied view of innate "modes of construal," see Keil 1995). In particular, the cognitive structure of folk biology specifies that generic species are the preferred kinds of things that partition the biological world, that these generic species are composed of causally related organisms that share the same vitalist (teleo-essentialist) structure, and that these generic species further group together into causally related but mutually exclusive groups under groups. In sum, the generic species is a core concept of the folk-biology module.

Core modules share much with Fodor's (1983) input modules. Both are presumably naturally selected endowments of the human mind that are initially activated by a predetermined range of perceptual stimuli. However, there are differences. Input modules, unlike core modules, are hermetically closed cognitive structures that have exclusive access to the mental representations that such input systems produce. For example, syntactic- recognition schemata and facial-recognition schemata respectively deal exclusively and entirely with syntactic recognition and facial recognition. By contrast, core modules have preferential rather than proprietary access to their domain-specific representations (Atran 1990:285). For example, core modules for naive physics, intuitive psychology or folk biology can make use of one another's inputs and outputs, although each module favors the processing of a different predetermined range of stimuli.

Moreover, the ability to use a "metarepresentational module," which takes as inputs the outputs of all other modules, allow changes (restructurings and extensions) to operate over the initial core domain as a result of developing interactions with our external (ambient) and internal (cognitive) environment. Flexibility in core modules, Sperber (1994) argues, makes evolutionary sense of how humans so quickly acquire distinct sorts of universal knowledge, which individuals and cultures can then work on and modify in various ways. Sperber's discussion also indicates, in principle, how ordinary people and cognitive scientists can manage the "combinatorial explosion" in human information without simply making it all grist for an inscrutable central-processing mill.

A living kind module enables humans to apprehend the biological world spontaneously as a partitioning into essence-based generic species and taxonomically related groups of generic species. This directs attention to interrelated and mutually constraining aspects of the plant and animal world, such as the diverse and interdependent functioning of heterogeneous body parts, maturational growth, inheritance and natural parentage, disease and death. Eventually, coherent "theories" of these causal interrelations might develop under particular learning conditions (Carey 1985) or historical circumstances (Atran 1990). Such systematic elaboration of biological causality, however, is not immediately observable or accessible.

Core knowledge that is domain-specific should involve dedicated perceptual-input-analyzers, operating with little interference or second-guessing from other parts of the human conceptual system (Carey 1996, Gigerenzer in press). What might be the evolutionary algorithm that activates or triggers the living kind module's selective attention to generic species? In the absence of experiments or other reliable data, we can only speculate. Evidence from other core domains, such as naive physics and intuitive psychology, helps as both guide and foil to speculation about triggering algorithms for a living-kind module. For humans as well as animals, there is some evidence of at least two distinct but hierarchically related triggering algorithms, each involving a dedicated perceptual-input-analyzer that attends to a restricted range of information.

There is an algorithm that attends only to the external movements of rigid bodies that obey something like the laws of Newtonian mechanics in a high-friction environment. Thus, infants judge that an object moving on a plane surface will continue along that surface in a straight path until it stops, but will not jump and suspend itself in mid-air (Spelke 1990). There is also an algorithm that attends to the direction and acceleration of objects not predictable by "naive mechanics." If the motion pattern of one object on a computer screen centers on the position of another object, so that the first object circles around the second object, and speeds up towards or away from it, then infants judge the first object to be self-propelled or "animate" (Premack & Premack 1994).

Of course, algorithms for animateness and intentionality can lead to mistakes. They surely did not evolve in response to selection pressures involving two-dimensional figures moving across computer screens. These inhabitants of flatland just happen to fall within the actual domains to which the modules for animacy and intentionality spontaneously extend, as opposed to the proper domains for which the modules evolved (i.e., animate beings and intentional agents). Much as the actual domain of frog food-getting intelligence involves tongue flicking at dark points passing along a frog's field of vision, whereas the proper domain is more about catching flies (Sperber 1994).

Algorithms for animacy and intentionality do not suffice to discriminate just living kinds, that is, generic species. On the one hand, they fail to distinguish plants from non-living kinds. Yet people everywhere distinguish plants into generic species just as they do animals. An algorithm that cues in primarily on the relative movement of heterogeneous and diversely connected parts around an object's center of gravity probably plays an important role in discerning animals and plants (perhaps first as they move in the wind, then grow, etc.), although it too may initially err (plastic plants, perhaps clothes on a line). On the other hand, algorithms for animacy and intentionality fail to distinguish humans from nonhuman living kinds, that is, plants and animals.

It is animals and plants that are always individuated in terms of their unique generic species, whereas humans are individuated as both individual agents and social actors in accordance with inferred intentions rather than expected clusters of body parts. People individuate humans (as opposed to animals) with the additional aid of a variety of domain-specific "recognizers" for individual human faces, voices, gestures and gaits, which richly motivate inferences about motion and intention from rather partial and fleeting perceptual cues (Fodor 1983, Tooby & Cosmides 1992). Yet no known aboriginal culture - or any culture not exposed to Aristotle - believes that humans are animals or that there is an ontological category undifferentiated between humans and animals.

Let us further speculate about selection pressures involved in our automatic attention to human individuals versus our automatic attention to generic species. A characteristic of primates (and some other vertebrates) is that they are social animals who can distinguish individuals of their species, unlike termites who cannot (Kummer, Daston, Gigerenzer & Silk in press). There is evidence that as long as two million years ago, Homo habilis relied upon nonkin to hunt, gather and scavenge for subsistence (Isaac 1983). In order to handle the social contracts required for this mode of subsistence, coalition forming and cooperation with nonkin were probably required. This probably entailed a negotiation of intentions with individuals who could not be identified by indications of blood relationship.

In regard to animals and plants, there is also evidence of varied and wide-ranging diet and subsistence patterns in hominid social camps at that time (Bunn 1983). In such a camp, it could be supremely important to know which individual should be recruited in a food-sharing coalition if only to avoid "free riders" who take without giving (Cosmides & Tooby 1989). But it would hardly matter to know the individual identity of lions which could eat you, nettles which could sting you, or deer and mangos which you could eat. Knowing not just the habits of particular species, but making taxonomic inferences about the habits and relationships of groups of biologically related species would be likely to increase the effectiveness (benefit) of such knowledge-based subsistence immeasurably, with little or no added investment (cost) in time or effort (trial-and-error learning).

The special evolutionary origins of domain-specific cognitive modules should have special bearings on cultural evolution. One might have expected the implications of domain-specificity to be compelling for those who reason in line with Dawkins (1976), viewing the emergence of culture as a selection process. Unfortunately, aside from notable exceptions (Sperber 1994; Tooby & Cosmides 1992; cf. Lumsden & Wilson 1981), the focus is primarily on how, for example, "Chinese minds differ radically from French minds" (Dennett 1995:365; cf. Cavalli-Sforza & Feldman 1981; Durham 1991). Nevertheless, Dawkins's idea may be a good idea for the study of human cultures, suitably modified by the findings and concerns of cognitive anthropology. His idea is that there may be cultural units that function in social evolution just as there are biological units that function in biological evolution. He calls these units of cultural transmission "memes" - a word that sounds like "gene" and evokes Latin and Greek words for "imitation." One modification consists in restricting highly imitative, replicating memes to knowledge produced by core domains, that is, to memes that have an identifiable syntactic as well as a semantic aspect. In this respect, folk-biological knowledge is a core meme.

A core meme, like universal taxonomy, differs from a developing meme, like the culturally specific elaboration of a scientific research program, in a number of interrelated ways. An apparent difference is in the closer resemblance of core memes to genes. First, for core memes, like genes, there is a strong alignment of syntactic ("genotypic") and semantic ("phenotypic") identity. For example, the universal structure of folk-biological taxonomy arguably emerges from a modular cognitive capacity - a mental faculty - that evolved as an effective means of capturing perceptibly relevant and recurrent aspects of ancestral hominid environments.

As a result, humans "conceptually perceive" the biological world in more or less the same way. Processes of perceiving and reasoning about generic species are intimately connected: they are guided by the same knowledge system. The folk-biology module focuses attention on perceptual information that can reveal that an object is a living kind, or organism, by uniquely assigning it to one or another of the fundamental partitions of the readily perceptible biological world. Thus, the key feature of folk biology, belonging to a preferred taxonomic rank and a causally essential category, is induced from spatiotemporal analysis via a triggering algorithm that attends to a limited set of perceptual cues whose presence signals an organism as belonging to a generic species.

Second, for core memes, conceptual replication involves information being physically transmitted largely intact from physical vehicle to physical vehicle without any appreciable sequencing of vehicles. As in genetic replication, replication of core memes involves fairly high-fidelity copying and a relatively low rate of mutation and recombination. Mental representations of generic species, for instance, are transmitted from brain to brain via public representations such as uttered names and pointings (Sperber 1985). It often suffices, however, that a single fragmentary instance of experience - a naming or sighting by ostension in a natural or artificial setting - "automatically" triggers the transmission and projection of that instance into a richly structured taxonomic context (Atran and Sperber 1991).

By contrast, a developing meme requires institutionalized channeling of information. For example, specific scientific schools or research programs involve more or less identifiable communities of scientists, journals, instruments, laboratories and so forth. Institutionalization is necessary because the information is harder to learn and keep straight, but is also more readily transformed and extended into new or different knowledge. This often requires formal or informal instruction to sustain the sequencing of information, and to infuse output with added value by inciting or allowing transformation of input via interpolation, invention, selection, suppression and so forth (see Latour 1987 and Hull 1988 for different insights into institutional constraints).

Third, a core meme does not depend for its survival on the cognitive division of labor in a society or on durable transmission media. For example, children can learn about species from written texts, films or picture books; nevertheless, noninstitutionalized transmission of such information in an illiterate society is usually quite reliable as long as there is an unbroken chain of oral communication (within the living memory of the collective) about events in the natural world. Developing memes, however, typically mobilize information of such quantity, diverse quality and expertise that single minds cannot - for lack of capacity or because of other cognitive demands - keep track of all that is needed to understand the information and pass it along. Because scientists can usually only work on bits and pieces of the information in the field at any particular time and place, but may also need to consult information elaborated elsewhere or let fallow for generations (e.g., Mendel's discoveries), durable media are required for that information to usefully endure.

Fourth, a core meme does not primarily depend on metacognitive abilities, although it may make use of them (e.g., in stories, allegories, analogies). For the harder-to-learn beliefs of developing memes to grow requires the mingling of ideas from different sources, including different sorts of core memes. For example, numerical and mechanical knowledge now play important, and perhaps preponderant, roles in areas of molecular biology. Mingling of ideas implies the transfer of diverse domain-specific outputs into a domain-neutral representation. A domain-neutral metarepresentation can then function as input for further information processing and development.

Fifth, the involvement of core memes in developing metacognitive memes that ride piggyback on core memes or stem from them, such as totemism or biological systematics, allows us in principle to distinguish the convergent evolution of memes across cultures from borrowing, diffusion and descent. If all memes were purely semantic, such a distinction might well be practically impossible in the absence of clear historical traces. One case of convergent evolution is the spontaneous emergence of totemism - the correspondence of social groups with generic species - at different times and in different parts of the world. Why, as Lèvi-Strauss (1963) aptly noted, are totems so "good to think"? In part, totemism is metacognitive because it uses representations of generic species to represent groups of people; however, this pervasive metarepresentational inclination arguably owes its recurrence to its ability to ride piggyback on folk-biological taxonomy, which is not primarily or exclusively metacognitive. Consider:

Generic species and groups of generic species are inherently well-structured, attention-arresting, memorable and readily transmissible across minds. As a result, they readily provide effective pegs on which to attach knowledge and behavior of less intrinsically well-determined social groups. In this way totemic groups can also become memorable, attention-arresting and transmissible across minds. These are the conditions for any meme to become culturally viable (see Sperber 1996 for a general view of culture along the lines of an "epidemiology of representations"). A significant feature of totemism that enhances both memorability and its capacity to grab attention is that it violates the general behavior of biological species: members of a totem, unlike members of a generic species, generally do not interbreed, but only mate with members of other totems in order to create a system of social exchange. Notice that this violation of core knowledge is far from arbitrary. In fact, it is such a pointed violation of human beings' intuitive ontology that it readily mobilizes most of the assumptions people ordinarily make about biology in order to better help build societies around the world (Atran & Sperber 1991).

In the structuring of such metarepresentations, then, the net result appears close to an optimal balance between memorability, attention-grabbing power and flexibility in assimilating and adapting to new and relevant information. This is to assure both ease of transmissibility and longstanding cultural survival. More generally, incorporating recurrently emerging themes in religious and symbolic thought into cognitive science can be pursued as a research program, which focuses on the transmission metarepresentational elaborations of intuitive ontologies or core memes (see Boyer 1994 for such a general framework for the study of religion).

This distinction between convergent and descendant metacognitive memes is not absolute. Creationism, for example, has both cross-culturally recurrent themes of supernatural species reification and particular perspectives on the nature of species that involve outworn scientific theories as well as specific historical traditions. Here as well, knowledge of the universal core of such beliefs helps to identify what is, and what is not, beyond the range of ordinary common sense (Atran 1990). Finally, even aspects of the metarepresentational knowledge that science produces as ouput can feed back (as input) in subtle and varied ways into the core module's actual domain: for example, learning that whales aren't fish and that bats aren't birds. But the feedback process is also constrained by the intuitive bounds of domain-specific, common sense (Atran 1987b).

The message here is that evolutionary psychology might profit from a source barely tapped: the study of cultural transmission. Some bodies of knowledge have a life of their own, only marginally affected by social change (e.g., intuitive mechanics, basic color classification, folk-biological taxonomies); others depend for their transmission, and hence for their existence, on specific institutions (e.g., totemism, creationism, evolutionary biology).[10] This suggests that culture is not an integrated whole, relying for its transmission on undifferentiated cognitive abilities. But the message is also one of "charity" concerning the mutual understanding of cultures (Davidson 1984): anthropology is possible because underlying the variety of cultures are diverse but universal commonalities. This message also applies to the disunity and comprehensibility of science (part 3).

2. Cultural Elaborations of Universal Taxonomy

Despite the evident primacy of ranked taxonomies in the elaboration of folk-biological knowledge in general, and the cognitive preference for generic species in particular, I no longer think that folk taxonomy defines the inferential character of folk biology as strongly as I indicated in a previous work, Cognitive Foundations of Natural History (Atran 1990). Mounting empirical evidence gathered with colleagues suggests that although universal taxonomic structures universally constrain and guide inferences about the biological world, different cultures (and to a lesser extent different individuals within a culture) show flexibility in which inferential pathways they choose (for details see Atran 1995, in press; Medin et al. 1996, 1997; Lûpez, Atran, Coley, Medin & Smith 1997; Coley, Medin, Proffitt, Lynch & Atran in press). Different tendencies apparently relate to different cultural criteria of relevance for understanding novelties and uncertainties in the biological world and in adapting to them.

For example, among the Itzaj Maya, in contrast to the systematic use of taxonomies by scientists or modern (non-aboriginal) American folk, understanding ecological relationships seems to play a role on a par with morphological and underlying biological relationships in determining how taxa may be causally interrelated. For centuries, Itzaj have managed to so use their folk-biological structures to organize and maintain a fairly stable, context-sensitive biological and ecological order. In a different way, scientists use taxonomies as heuristics for reaching a more global, ecologically context-free understanding of biological relationships underlying the diversity of life. American folk unwittingly pursue a compromise of sorts: maintaining ecologically valid folk categories, but reasoning about them as if they were theory-based. Irrelevancy often results.

2.1. Taxonomy-Based Inference Across Cultures.

To illustrate, consider some recent experimental findings. Our intention was to see whether and how Americans and Maya reason the same or differently from their respective taxonomies to determine the likely distribution of unfamiliar biologically-related properties. Our strategy was as follows: First we asked individual informants to perform successive sorting tasks of name cards or colored picture cards (or specimens in Itzaj pilot studies) in order to elicit individual taxonomies. Then we used statistical measures to see whether or not the data justified aggregating the individual taxonomies for each informant group into a single "cultural model" that could confidently retrodict most (of the variance in) informant responses. Finally, we used the aggregated cultural taxonomies to perform various category-based inference tasks with the same or different informants. At each stage of the sorting and inference tasks we asked informants to justify responses. In sum, our techniques enabled us to describe an aggregate model of taxonomy for each population in order to determine emergent patterns of cultural preferences in matters of biological inference.

2.1.1. An Experimental Method for Generating Taxonomies.

In the sorting tasks, each set of cards represented either all the generic species of a life form (Itzaj and Michigan mammals) or intermediate category (Itzaj palms), or a large range of the generic species of a life form (e.g., all local trees in the Evanston-Chicago area for people living in the area). The aim was to obtain individual taxonomies that covered the range of relationships between intermediate folk taxa, that is, taxonomic relationships between the generic-species and life-form levels. This was motivated by the fact that the boundaries of intermediate taxa vary somewhat more across individuals and cultures than do ranked taxa, and our goal was to explore as much the differences as the similarities in taxonomy-based reasoning across cultures. Furthermore, the intermediate level of taxonomy is where evolutionary relationships are most visibly manifest and comprehensible (both in the history of science and among educated lay folk, see Atran 1983), and where ecological relationships are most manifest for Maya (e.g., in the habits of arboreal mammals on the fruiting and reproduction of canopy trees). We thought these factors would increase the possibility of ascertaining whether significant differences between Americans and Maya relate to different goals for understanding biological relationships: one weighted by the influence of science in American culture, and the other weighted by interests of subsistence and survival in the Maya rainforest.

2.1.1.1. Methods.

What follows is a brief account of findings in regard to all mammals represented in the local environments of the Itzaj and Michigan groups, respectively.[11] For Itzaj we included bats, although Itzaj do not consider them mammals. For the students we included the emblematic wolverine, although it has practically disappeared from Michigan. We asked American informants to sort name cards of all local mammal generic species into successive piles according to the degree they "go together by nature." For Itzaj, name cards were Maya words in Latin letters and informants were asked to successively sort cards according to the degree to which they "go together as companions" (uy-et'~ok) of the same "natural lineage" (u-ch'ib'al). When informants indicated no further desire to successively groups cards the first piles were restored and the informants were asked to subdivide the piles until they no longer wished to do so. The "taxonomic distance" between any two taxa (cards) was then calculated according to where in the sorting sequence they were first grouped together. While a majority of Itzaj informants were functionally illiterate, they had no trouble in manipulating name cards as mnemonic icons. No differences were observed in handling cards between literate and illiterate Itzaj, and no statistically significant differences in results. We chose names cards over pictures or drawings to minimize stimulus effects and maximize the role of categorical knowledge.

2.1.1.2. Results: Convergence and Divergence in Intermediate-Level classifications.

Results indicate that the individual mammal taxonomies of Itzaj and students from rural Michigan are all more or less competent expressions of comparably robust cultural models of the biological world.[12] To compare the structure and content of cultural models with one another, and with scientific models, we mathematically compared the topological relations in the tree structure of each group's aggregate taxonomy with those of a classic evolutionary taxonomy, that is, one based on a combination of morphological and phylogenetic considerations.[13]

There was substantial shared agreement between the aggregated taxonomies of Itzaj (Figure 3) and Michigan students (Figure 4), between evolutionary taxonomy (Figure 5) and Itzaj taxonomy, and between evolutionary taxonomy and the American folk taxonomy. Agreement between the intermediate folk taxonomies and evolutionary taxonomy is maximized at around the level of the scientific family, both for Itzaj and Michigan subjects, indicating an intermediate-level focus in the folk taxonomies of both cultures. On the whole, taxa formed at this level are still imageable (e.g., the cat or dog families).

A closer comparison of the folk groupings in the two cultures, however, suggests that there are at least some cognitive factors at work in folk-biological classification that are mitigated or ignored by science. For example, certain groupings, such as felines + canines, are common to both Itzaj and Michigan students, although felines and canines are phylogenetically further from one another than either family is to other carnivore families (e.g., mustelids, procyonids, etc.). These groupings of large predators indicate that size and ferocity or remoteness from humans is a salient classificatory dimensions in both cultures (cf. Henley 1969, Rips et al. 1973). These are dimensions that a corresponding evolutionary classification of the local fauna does not highlight.

An additional nonscientific dimension in Itzaj classification, which is not present in American classification, relates to ecology. For example, Itzaj form a group of arboreal animals, including monkeys as well as tree-dwelling procyonids (kinkajou, cacomistle, raccoon) and squirrels (a rodent). The ecological nature of this group was independently confirmed as follows: We asked informants to tell us which plants are most important for the forest to live. Then, we aggregated the answers into a cultural model, and for each plant in the aggregate list we asked which animals most interacted with it (without ever asking directly which animals interact with one another). The same group of arboreal animals emerged as a stable cluster in interactions with plants.

Other factors in the divergence between folk and scientific taxonomies are related both to science's global perspective in classifying local biota and to its reliance on biologically "deep," theoretically weighted properties of internal anatomy and physiology. Thus, the opossum is the only marsupial in North and Central America. Both Itzaj and Midwesterners relate the opossum to skunks and porcupines because it shares with them readily perceptible features of morphology and behavior. From a scientific vantage, however, the opossum is taxonomically isolated from all the other locally represented mammals in a subclass of its own. One factor mitigating the ability of Itzaj or Midwesterners to appreciate the opossum as scientists do is the absence of other locally present marsupials to relate the opossum to. As a result, both Michigan students and Itzaj are apparently unaware of the deeper biological significance of the opossum's lack of a placenta.

2.1.2. Taxonomy-Driven Inductions.

Our inference studies were designed to further explore how the underlying reasons for these these apparent similarities and differences in intermediate-level taxonomies might inform category-based inductions among Maya, lay Americans and scientists. We tested for three category-based induction phenomena: Taxonomic Similarity, Taxonomic Typicality and Taxonomic Diversity (cf. Osherson, Smith, Wilkie, Lûpez & Shafir 1990).

2.1.2.1 Taxonomic Similarity.

Similarity involves judging whether inference from a given premise category to a conclusion category is stronger than inference from some other premise to the same conclusion, where the premise and conclusion categories are those in the aggregate taxonomic tree. Similarity predicts that the stronger inference should be the one where the premise is closest to the conclusion, with "closeness" measured as the number of nodes in the tree one has to go through to reach the conclusion category from the premise category. So, suppose that sheep have some unfamiliar property (e.g., "ulnar arteries") or are susceptible to an unknown disease ("eta"). Suppose, as an alternative premise, that cows have a different property ("sesamoid bones") or are susceptible to a different disease (e.g., "ina"). Following any of the three taxonomies (Maya, American or evolutionary), one should conclude that is it more likely that goats have what sheep have than what cows have, because goats are taxonomically closer to sheep than they are to cows.

If similarity is a built-in feature of folk taxonomy, then American and Maya inductions should converge and diverge where their taxonomies do. They should also resemble and depart from scientific inductions where their taxonomies do regarding the scientific taxonomy. In fact, both Americans and Maya chose items like sheep/goat versus cow/goat. This confirms the convergence of the scientific taxonomy with reasoning among both Americans and Maya precisely where the structure of their respective taxonomies should lead us to expect convergence.

Both also chose items like opossum/porcupine versus squirrel/porcupine, which confirms the expected convergence between Maya and American classifications, and also the expected divergence of both groups from scientific classification. Choice of items such as dog/fox for Americans but cat/fox for Maya confirms that Americans reason more in line with scientific classifications in such cases than do Maya. In fact, justifications show that Itzaj recognize numerous similarities between foxes and dogs (snout, paw, manner of copulation) but judge that foxes are closer to cats because of interrelated aspects of size and predatory habits.

2.1.2.2. Taxonomic Typicality.

The metric for typicality, like the one for similarity, is given by the taxonomy itself, as the lowest average taxonomic distance. In other words, the typicality of an item (e.g., a generic species) is the average taxonomic distance of that item to all other items in the inclusive category (e.g., life form). Items that are more typical provide greater coverage of the category than items that are less typical. For example, Itzaj choose the items jaguar/mammal or mountain lion/mammal over squirrel/mammal or raccoon/mammal, judging that all mammals are more like to be susceptible to a disease that jaguars or mountain lions have than to a disease that squirrels or raccoons have.

This is because Maya consider jaguars and mountain lions more typical of the mammals than are squirrels and raccoons. In fact, jaguars and mountain lions are not merely typical for Itzaj because they are more directly related to other mammals than are squirrels and raccoons; they also more closely represent an ideal standard of the "true animal/mammal" (jach b'a'al~che') against which the appearance and behavior of all other animals may be judged. This is evident from Itzaj justifications as well as from direct ratings of which mammals the Itzaj consider to be the "truest."

By contrast, American informants choose the items squirrel/mammal or raccoon/mammal over bobcat/mammal or lynx/mammal, presumably because they consider squirrels and raccoons are more typical of mammals for Americans than are bobcats and lynxes. Note that typicality in these cases cannot be attributed to frequency of occurrence or encounter. Our American subjects were all raised in rural Michigan, where the frequency of encounter with squirrels, raccoons, bobcats and lynxes is nowadays about as likely as the corresponding Itzaj encounter with squirrels, raccoons, jaguars and mountain lions. Both the Americans and Maya were also more or less familiar with all animals in their respective tasks.

In each case for which we have Itzaj typicality ratings, the "truest" and most taxonomically-typical taxa are large, perceptually striking, culturally important and ecologically prominent. The dimensions of perceptual, ecological and cultural salience all appear necessary to a determination of typicality, but none alone appears to be sufficient. For example, jaguars are beautiful and big (but cows are bigger), their predatory home range (about 50 km2) determines the extent of a forest section (but why just this animal's home range?), and they are "lords" of the forest (to which even the spirits pay heed). In other words, typicality for the Itzaj appears to be an integral part of the human (culturally-relevant) ecology. Thus, the Itzaj say that wherever the sound of the jaguar is not heard, there is no longer any "true" forest, nor any "true" Maya. Nothing of this sort appears to be the case with American judgments of biological typicality and typicality-based biological inference. Thus, the wolverine is emblematic in Michigan, but carries no preferential inductive load.

2.1.2.3. Taxonomic Diversity.

Like taxonomically defined typicality, diversity is a measure of category coverage. But a pair of typical items provides less coverage than, say, a pair containing one item that is typical and another that is atypical. For example, given that horses and donkeys share some property, but that horses and gophers share some other property, then our American subjects judge that all mammals are more likely to have the property that horses share with gophers than the property that horses share with donkeys. This is because the average taxonomic distance of donkeys to other mammals is about the same as that of horses, so that donkeys add little information that could not be inferred from horses alone. For example, the distance from horses and donkeys to cows is uniformly low, whereas the distance to mice is uniformly high. Now, the distance from horses to cows is low, but so is the distance from gophers to mice. Thus, information about both horses and gophers is likely to be more directly informative about more mammals than information about only horses and donkeys.

Whereas both Americans and Itzaj consistently show similarity and typicality in taxonomy-based reasoning, the Itzaj do not show diversity. However, Itzaj noncompliance with diversity-based reasoning apparently results neither from a failure to understand the principle of diversity nor from any problems of "computational load," such as those which seem to affect the inability of young school children to reason in accordance with diversity (Lûpez, Gelman, Gutheil & Smith 1992). As with the most evident divergences between American and Itzaj performance on similarity and typicality tasks, divergence on diversity apparently results from ecological concerns.

The diversity principle corresponds to the fundamental principle of induction in scientific systematics: a property shared by two organisms (or taxa) is likely shared by all organisms falling under the smallest taxon containing the two (Warburton 1967). Thus, American folk seem to use their biological taxonomies much as scientists do when given unfamiliar information in order to infer what is likely in the face of uncertainty: informed that goats and mice share a hitherto unknown property, they are more likely to project that property to mammals than if informed that goats and sheep do. By contrast, Itzaj tend to use similarly structured taxonomies to search for causal ecological explanations of why unlikely events should occur: for example, bats may have passed on the property to goats and mice by biting them, but a property does not need an ecological agent to be shared by goats and sheep.

In the absence of a theory - or at least the presumption of a theory - of causal unity underlying disparate species, there is no compelling reason to consider a property discovered in two distant species as biologically intrinsic or essential to both. It may make as much or more sense to consider the counterintuitive presence of a property in dissimilar species as the likely result of an extrinsic or ecologically "accidental" cause. Notice that in both the American and Itzaj cases similarly structured taxonomies provide distance metrics over which biological induction can take place. For the Americans, taxonomic distance generally indicates the extent to which underlying causes are more likely to predict shared biological properties than are surface relationships. For Itzaj, taxonomic distance offers one indication of the extent to which ecological agents are likely to be involved in predicting biological properties that do not conform to surface relationships.

A priori, either stance might be correct. For example, diseases are clearly biologically-related; however, distribution of a hitherto unknown disease among a given animal population could well involve epidemiological factors that depend on both inherent biological susceptibility and ecological agency. Equally "appropriate" ecological strategies may be used to reason about unfamiliar features of anatomy, physiology and behavior (e.g., in regard to predators or grazers), and even reproduction and growth (e.g., possible animal hybridizations or plant graftings).[14]

This does not mean that Itzaj do not understand a diversity principle. In their justifications, Itzaj clearly reject a context-free use of the diversity-principle in favor of context-sensitive reasoning about likely causal connections. In fact, in a series of tasks designed to assess risk-diversification strategies (e.g., sampling productivity from one forest plot or several) Itzaj consistently showed an appreciation of the diversity principle in these other settings. This suggests that although diversity may be a universal reasoning heuristic it is not a universal aspect of folk-biological taxonomy.

More generally, what "counts" as a biological cause or property may differ somewhat for folk, like the Itzaj, who necessarily live in intimate awareness of their surroundings, and those, like American folk, whose awareness is less intimate and necessary. For Itzaj, awareness of biological causes and properties may directly relate to ecology, whereas for most American folk the ecological ramifications of biological causes and properties may remain obscure. Historically, the West's development of a world-wide scientific systematics explicitly involved disregard of ecological relationships, and of the colors, smells, sounds, tastes and textures that constitute the most intimate channels of Maya recognition and access to the surrounding living world. For example, the smell of animal excrement so crucial to Maya hunters, or the texture of bark so important to their recognition of trees in the dark forest understory, simply have no place in a generalized and decontextualized scientific classification.

2.1.2.4. Science's Marginal Role for American Folk.

A good candidate for the cultural influence of theory in American folk biology is science. Yet, the exposure of Michigan students to science education has little apparent effect on their folk taxonomy. From a scientific view, student taxonomies are no more accurate than those of Itzaj. Science's influence is at best marginal. For example, science may peripherally bear on the differences in the way Itzaj and Michigan students' categorize bats. Itzaj deem bats to be birds (ch'iich'), not mammals (b'a'al~che').

Like Midwesterners, Itzaj acknowledge in interviews that there is a resemblance between bats and small rodents. Because Itzaj classify bats with birds, they consider the resemblance to be only superficial and not indicative of a taxonomic relationship. By contrast, Michigan students "know" from schooling that bats are mammals. But this knowledge can hardly be taken as evidence for the influence of scientific theory on folk taxonomy. Despite learning that bats are mammals, the students go on to relate bats to rats just as Itzaj might if they did not already "know" that bats are birds. Nevertheless, from an evolutionary standpoint bats are taxonomically no closer to rats than to cats. The students, it seems, pay scant attention to the deeper biological relationships science reveals. In other words, the primary influence of science education on folk-biological knowledge may be to fix category labels, which in turn may affect patterns of attention and induction.

The influence of science education on folk induction may also reflect less actual knowledge of theory than willing belief that scientific theory supports folk taxonomy. For example, given that a skunk and opossum share a deep biological property, Michigan students are less likely to conclude that all mammals share the property than if it were shared by a skunk and a coyote. From a scientific standpoint, the students employ the right reasoning strategy (diversity-based inference), but reach the wrong conclusion because of a faulty taxonomy (i.e., the belief that skunks are taxonomically further from coyotes than from opossums). Yet if told that opossums are phylogenetically more distant from skunks than coyotes are, the students readily revise their taxonomy to make the correct inference. Still, it would be misleading to claim that the students then use theory to revise their taxonomy, although a revision occurs in accordance with scientific theory.

2.1.3. A Failing Compromise.

With their ranked taxonomic structures and essentialist understanding of species, it would seem that no great cognitive effort is additionally required for the Itzaj to recursively essentialize the higher ranks as well, and thereby avail themselves of the full inductive power ranked taxonomies provide. But contrary to earlier assumptions (Atran 1990), our studies show this is not the case. Itzaj, and probably other traditional folk, do not essentialize ranks: they do not establish causal laws at the intermediate or life-form levels, and do not presume that higher-order taxa share the kind of unseen causal unity that their constituent generic species do.

There seems, then, to be a sense to Itzaj "failure" in turning their folk taxonomies into one of the most powerful inductive tools that humans may come to possess. To adopt this tool, Itzaj would have to suspend their primary concern with ecological and morpho-behavioral relationships in favor of deeper, hidden properties of greater inductive potential. But the cognitive cost would probably outweigh the benefit (Sperber & Wilson 1986). For this potential, which science strives to realize, is to a significant extent irrelevant, or only indirectly relevant, to local ecological concerns.

Scientists use diversity-based reasoning to generate hypotheses about global distributions of biological properties so that theory-driven predictions can be tested against experience and the taxonomic order subsequently restructured when prediction fails. By contrast, American folk do not have the biological theories to support diversity-based reasoning that scientists do. If they did, American folk would not have the categories they do.

2.2. The General-Purpose Nature of Folk Taxonomy.

These experimental results in two very different cultures - an industrial Western society and a small-scale tropical forest society - indicate that people across cultures organize their local flora and flora in similarly structured taxonomies. Yet they may reason from their taxonomies in systematically different ways. These findings, however, do not uphold the customary distinction in anthropology and in history and philosophy of biology, between "general-purpose" scientific classifications that are designed to maximize inductive potential and "special-purpose" folk-biological classifications (Gilmour & Walters 1964, Bulmer 1970), which are driven chiefly by "functional" (Duprè 1981), "utilitarian" (Hunn 1982) or "social" (Ellen 1993) concerns. On the contrary, like scientific classifications folk-biological taxonomies appear to be "general-purpose" systems that maximize inductive potential for indefinitely many inferences and ends. That potential, however, may be conceived differently by a small-scale society and a scientifically oriented community.

For scientific systematics, the goal is to maximize inductive potential regardless of human interest. The motivating idea is to understand nature as it is "in itself," independently of the human observer (as far as possible). For the Itzaj, and arguably for other small-scale societies, folk-biological taxonomy works to maximize inductive potential relative to human interests. Here, folk-biological taxonomy provides a well-structured but adaptable framework . It allows people to explore the causal relevance to them - including the ecological relevance - of the natural world, and in indefinitely many and hitherto unforeseen ways. Maximizing the human relevance of the local biological world - its categories and generalizable properties (including those yet undiscovered) - does not mean assigning predefined purposes or functional signatures to it. Instead, it implies providing a sound conceptual infrastructure for the widest range of human adaptation to surrounding environmental conditions, within the limits of culturally acceptable behavior and understanding.

For scientific systematics, folk biology may represent a ladder to be discarded after it has been climbed, or at least set aside while scientists surf the cosmos. But those who lack traditional folk knowledge, or implicit appreciation of it, may be left in the crack between science and common sense. For an increasingly urbanized and formally educated people, who are often unwittingly ruinous of the environment, no amount of cosmically valid scientific reasoning skill may be able to compensate the local loss of ecological awareness upon which human survival may ultimately depend.

3. Science and Common Sense in Systematic Biology

The scenario that I have explored so far comes to this: Some areas of culture in general, as well as particular scientific fields, are based in specific cognitive domains that are universal to human understanding of nature. Concern with elaborating this basis produces recurrent themes across cultures (e.g., totemism), and its evaluation constitutes much of the initial phases in the development of a science (e.g., natural history). The next sections take a closer look at later phases in the development of systematic biology, where knowledge of the world comes to transcend the bounds of sense without, however, completely losing sight.

The experimental evidence reviewed in the previous sections suggests that people in small-scale, traditional societies do not spontaneously extend assumptions of an underlying essential nature to taxa at ranks higher than the generic species. Thus, to infer that a biological property found in a pair of organisms belonging to two very different looking species (e.g., a chicken and an eagle) likely belongs to all organisms in the lowest taxon containing the pair (e.g., bird) may require a reflective elaboration of causal principles that are not related to behavior, morphology, or ecological proclivity in any immediately obvious way. Only this would justify the assumption that all organisms belonging to a taxon at a given rank share equally some internal structure regardless of apparent differences between them.

Such predictions lead to errors as well as discoveries. This sets into motion a "boot-strapping" reorganization of taxa and taxonomic structure, and of the inductions that the taxonomy supports. For example, upon discovery that bats bear and nurture their young more like mammals than birds, it is then reasonable to exclude bats from bird and include them with mammal. Despite the "boot-strapping" revision of taxonomy implied here, notice how much did not change: neither the overall structure of folk taxonomy, nor - in a crucial sense - even the kinds involved. Bats, birds, whales, mammals and fish did not just vanish from common sense to arise anew in science. There was a redistribution of affiliations between antecedently perceived kinds. What had altered was the construal of the underlying natures of those kinds, with a redistribution of kinds and a reappraisal of properties pertinent to reference.

Historically, taxonomy is conservative, but it can be revolutionized. Even venerable life forms, like tree, are no longer scientifically valid concepts because they have no genealogical unity (e.g., legumes are variously trees, vines, bushes, etc.). The same may true of many longstanding taxa. Phylogenetic theorists question the "reality" of zoological life forms, such as bird and reptile, and the whole taxonomic framework that made biology conceivable in the first place. Thus, if birds descended from dinosaurs, and if crocodiles but not turtles are also directly related to dinosaurs, then: crocodiles and birds form a group that excludes turtles; or crocodiles, birds and turtles form separate groups; or all form one group. In any event, the traditional separation of bird and reptile is no longer tenable.

Still, even in the midst of their own radical restructuring of taxonomy, Linnaeus and Darwin would continue to rely on popular life-forms like tree and bird to collect and understand local species arrangements, as do botanists and zoologists today. As for ordinary people, and especially those who live intimately with nature, they can ignore such ecologically salient kinds only at their peril. That is why science cannot simply subvert common sense.

3.1. Aristotelian Essentials.

The boot-strapping enterprise in Western science began with Aristotle, or at least with the naturalistic tradition in Ancient Greece he represented. His task was to unite the various foundational forms of the world - each with their own special underlying nature" (phusis in the implicit everyday sense) - into an overarching system of "Nature" (phusis in an explicitly novel metaphysical sense). In practice, this meant systematically deriving each generic species (atomon eidos) from the causal principles uniting it to other species of its life form (megiston genos). It also implied combining the various life forms by "analogy" (analogian) into an integrated conception of life. Theophrastus, Aristotle's disciple, conceived of botanical classification in a similar way.

Aristotelian life forms are distinguished and related through possession of analogous organs of the same essential function (locomotion, digestion, reproduction, respiration). For example, bird wings, quadruped feet and fish fins are analogous organs of locomotion. The generic species of each life form are then differentiated by degrees of "more or less" with respect to essential organs. Thus, all birds have wings for moving about and beaks for obtaining nutriments. But, whereas the predatory eagle is partially diagnosed by long and narrow wings and a sharply hooked beak, the goose - owing to its different mode of life - is partially diagnosed by a lesser and broader wing span and flatter bill. A principled classification of biological taxa by "division and assembly" (diaresis and synagoge) ends when all taxa are defined, with each species completely diagnosed with respect to every essential organ (Atran 1985b).

In the attempt to causally link up all taxa, and derive them from one another, Aristotle took the first step in decontextualizing nature from its ecological setting. For him, birds were not primarily creatures that live in trees and the air, but causal complexes of life's essential organs and functions from which generic species derive. Life forms become causal way stations in the essential processes that link the animal and plant kingdoms to generic species. As a result, all higher ranks are now essentialized on a par with generic species, and the principle of taxonomic diversity becomes the basis for causal inference in systematics: any biological property that can be presumed to be related to life's essential organs and functions, if shared by two generic species, can be expected to be shared in descending degrees by all organisms in the life form containing the two.

This first sustained scientific research program failed because it was still primarily a local effort geared to explaining a familiar order of things. Aristotle knew of species not present in his own familiar environment, but he had no idea that there were orders of magnitude of difference between what was locally apparent and what existed worldwide. Given the (wrong) assumption that a phenomenal survey of naturally occurring kinds was practically complete, he hoped to find a true and consistent system of essential characters by trial and error. He did not foresee that introduction of exotic forms would undermine his quest for a discovery of the essential structure of all possible kinds. But by inquiring into how the apparently diverse natures of species may be causally related to the nature of life, Aristotle established the theoretical program of natural history (as biology was called before evolutionary theory).

3.2. The Linnaean Hierarchy.

As in any folk inventory, ancient Greeks and Renaissance herbalists contended with only 500 or 600 local species (Raven et al. 1971). Preferred taxa often correspond to scientific species (dog, coyote, lemon tree, orange tree). But frequently a scientific genus has only one locally occurring species (bear, redwood), which makes species and genus perceptually coextensive. This occurs regularly with the most phenomenally salient organisms, including mammals and trees (for example, in a comparative study, we found that 69% of tree genera in both the Chicago area - 40 of 58 - and the Itzaj area of the Peten rainforest - 158 of 229 - are monospecific, see Medin et al. in press).

Europe's "Age of Exploration," which began during the Renaissance, presented the explorers with a dazzling array of new species. The emerging scientific paradigm required that these new forms be ordered and classified within a global framework that unaided common sense could no longer provide. This required a further decontextualizing of nature, which the newly developed arts of block printing and engraving allowed. In what is widely regarded as the first "true-to-nature" herbal of the Renaissance (Brunfels 1530-1536), a keen historian of science notes:

The plant was taken out of the water, and the roots were cleansed. What therefore we see depicted is a water lily without water - isn't this a bit paradoxical? All relations between the plant and its habitat have been broken and concealed (Jacobs 1980:162).

By isolating organisms from local habitats through the sense-neutral tones of written discourse, a global system of biological comparisons and contrasts could develop. This meant sacrificing local "virtues" of folk-biological knowledge, including cultural, ecological and sensory information.

In the Post-Renaissance, decontextualization of preferred folk taxa eventually led to their "fissioning" into species (Cesalpino 1583) and genera (Tournefort 1694). During the initial stages of Europe's global commercial expansion, the number of species increased an order of magnitude. Foreign species were habitually joined to the most similar European species, that is, to the generic type, in a "natural system." Enlightenment naturalists, like Jungius and Linnaeus, further separated natural history from its cognitive moorings in human ecology, banning from botany intuitively "natural" but scientifically "lubricious" life-forms, such as tree and grass (Linnaeus 1751, sec. 209).

A similar "fissioning" of intermediate folk groupings occurred when the number of encountered species increased another order of magnitude, and a "natural method" for organizing plants and animals into families (Adanson 1763) and orders (Lamarck 1809) emerged as the basis of modern systematics. Looking to other environments to complete local gaps at the intermediate level, naturalists sought to discern a worldwide series that would cover all environments and again reduce the ever-increasing number of discovered species to a mnemonically manageable set - this time to a set of basic, family plans. Higher-order vertebrate life forms were left to provide the initial framework for biological classes, which only phylogenetic theory would call into question.

A concept of phylum became distinguished once it was realized that there is less internal differentiation between all the vertebrate life forms taken as a whole, than there is within most intermediate groupings of the phenomenally "residual" life form, insect (bugs, worms, etc.). This was due to Cuvier (1829), who first reduced vertebrates to a single "branch" (embranchement). Finally, climbing the modified ranks of folk biology to survey the diversity of life, Darwin was able to show how the whole ordering of species could be transformed into the tree of life - a single emerging Nature governed by the causal principles of natural selection.

3.3. Folk Biology's Enduring Embrace.

From Linnaeus to the present day, biological systematics has used explicit principles and organizing criteria that traditional folk might consider secondary or might not consider at all (e.g., the geometrical composition of a plant's flower and fruit structure, or the numerical breakdown of an animal's blood chemistry). Nevertheless, as with Linnaeus, the modern systematist initially depends implicitly, and crucially, on a traditional folk appreciation. As Bartlett (1936:5) noted with specific reference to the Maya region of Peten (cf. Diamond 1966 for zoology):

A botanist working in a new tropical area is... confronted with a multitude of species which are not only new to him, but which flower and fruit only at some other season than that of his visit, or perhaps so sporadically that he can hardly hope to find them fertile. Furthermore, just such plants are likely to be character plants of [ecological] associations.... [C]onfronted with such a situation, the botanist will find that his difficulties vanish as if by magic if he undertakes to learn the flora as the natives know it, using their plant names, their criteria for identification (which frequently neglect the fruiting parts entirely), and their terms for habitats and types of land.

As Linnaeus needed the life form tree and its commons species to actually do his work, so did Darwin need the life form bird and its common species. From a strictly cosmic viewpoint, the title of his great work, On the Origins of Species, is ironic and misleading - much as if Copernicus had entitled his attack on the geocentric universe, On the Origins of Sunrise. Of course, in order to attain that cosmic understanding, Darwin could no more dispense with thinking about "common species" than Copernicus could avoid thinking about the sunrise (Wallace 1901:1-2). In fact, not just species, but all levels of universal folk taxonomy served as indispensable landmarks for Darwin's awareness of the evolving pathways of diversity: from the folk-specifics and varietals whose variation humans had learned to manipulate, to intermediate-level families, and life-form classes, such as bird, within which the godlier processes of natural selection might be discerned:

[In the Galapagos Islands] There are twenty-six land birds; of these twenty-one or perhaps twenty-three are ranked a distinct species, and would commonly be assumed to have been here created; yet the close [family] affinity of most of these birds to American species is manifest in every character, in their habits, gestures, and tones of voice. So it is with other animals, and with a large proportion of plants.... Facts such as these, admit of no sort of explanation on the ordinary view of creation. (Darwin 1872/1883:353-354).

Use of taxonomic hierarchies in systematics today reveals a similar point. By tabulating the ranges of extant and extinct genera, families, classes and so on, systematists can provide a usable compendium of changing diversity throughout the history of life. For example, by looking at just numbers of families, it is possible to ascertain that insects form a more diverse group than tetrapods (i.e, terrestrial vertebrates, including amphibians, birds, mammals and reptiles). By calculating whether or not the taxonomic diversity in one group varies over time as a function of the taxonomic diversity in another group, evidence can be garnered for or against the evolutionary interdependence of the two groups. Recent comparisons of the relative numbers of families of insects and flowering plants, reveal the surprising fact that insects were just as taxonomically diverse before the emergence of flowering plants as after. Consequently, evolutionary effects of plant evolution on the adaptive radiation of insects are probably less profound than previously thought (Labandeira & Sepkoski 1993). The heuristic value of (scientifically elaborated) folk-based strategies for cosmic inquiry is compelling, despite evolutionary theorists being well aware that no "true" distinctions exist between various taxonomic levels.

Not only do taxonomic structure and species continue to agitate science - for better or worse - but also the nonintentional and nonmechanical causal processes that people across the world assume to underlie the biological world. Vitalism is the folk belief that biological kinds - and their maintaining parts, properties and processes - are teleological, and hence not reducible to the contingent relations that govern inert matter. Its cultural expression varies (cf. Hatano & Inagaki 1994). Within any given culture people may have varying interpretations and degrees of attachment to this belief: some who are religiously inclined may think that a "spiritual" essence determines biological causality; others of a more scientific temperament might hold that systems of laws which suffice for physics and chemistry do not necessarily suffice for biology. Many, if not most, working biologists (including cognitive scientists) implicitly retain at least a minimal commitment to vitalism: they acknowledge that physico-chemical laws should suffice for biology, but suppose that such laws are not adequate in their current form, and must be enriched by further laws whose predicates are different from those of inert physics and chemistry.

It is not evident how a complete elimination of teleological expressions (concepts defined functionally) from biological theory can be pursued without forsaking a powerful and fruitful conceptual scheme for physiology, morphology, disease and evolution. In cognitive science, a belief that biological systems, such as the mind/brain, are not wholly reducible to electronic circuitry, like computers, is a pervasive attitude that implicitly drives considerable polemic, but also much creative theorizing. Even if this sort of vitalism represents a lingering folk belief that science may ultimately seek to discard, it remains an important and perhaps indispensable cognitive heuristic for regulating scientific inquiry.

3.4. Are there Folk Theories of Natural Kinds?

So far the line of argument has been that systematic biology and commonsense folk biology continue to share core-related concepts, such as the species, taxonomic ranking and teleological causality. Granted, in science these are used more as heuristics than as ontological concepts, but their use allows and fosters varied and pervasive interactions between science and common sense. Still, systematic biology and folk biology are arguably distinct domains, which are delimited by different criteria of relevance.

This cognitive division of labor between science and common sense is not a view favored in current philosophy or psychology (see Duprè 1993 for an exception). More frequent is the view that in matters of biological systematics, science is continuous with folk biology; only, science involves a more adequate elaboration of implicit folk meanings and "theories." Deciding the issue is not so simple - in part because, as Bertrand Russell lamented: "One of the most difficult matters in all of controversy is to distinguish disputes about words from disputes about facts" (1958:114).

Philosophers and psychologists have noted that no principled distinction between folk and scientific knowledge can be built on ideas of empirical refutation or confirmation, under-determination or going beyond appearance or the information given, or even toleration of internal contradictions and inconsistencies (Kuhn 1962, Feyerabend 1975, Keil & Silberstein 1996). Instead, I want to focus on three related differences between science and folk systems: integration, effectiveness and competition. Concerning integration, it does appear that across all cultures there is some attempt at causal coordination of a few central aspects of life: bodily functioning and maturational growth, inheritance and reproduction, disease and death. But the actual extent of this integration, and the concrete causal mechanisms that effect it, vary widely in detail and coherency across cultures (and individuals, judging by informant justifications in the experimental tasks discussed in the last section).

Although the core concept of a generic species as a teleological agent may be universal, knowledge of the actual causal chains that linkup the life properties of a species can involve a host of vitalistic, mechanical and intentional causes whose mix is largely determined by social tradition and individual learning experience (e.g., on disease, see Keil 1994 and Au & Romo 1996 for Americans, and Berlin & Berlin 1996 for Maya). Moreover, few, if any, commonsense accounts of "life" seek to provide a causal account of the global relationships linking (e.g., generating) species and groups of species to and from one another, although there may be various recurrent causal clusters and family relationships. Aristotle was possibly the first person in the world to attempt to integrate an entire taxonomic system.[15]

Concerning effectiveness, science's aim is ultimately cosmic in that it is geared to generating predictions about events that are equally accurate, correct or true for any observer. By contrast basic commonsense knowledge, driven by the folk core, has a more terrestrial aim: namely, to provide an effective understanding of the environment that allows appropriate responses. From an evolutionary standpoint, the structure from which we infer an agent's environment must also be the one that actively determines the agent's behavioral strategies (congruent actions and responses): "if the resulting actions anticipate useful future consequences, the agent has an effective internal model; otherwise it has an ineffective one" that may lead it to die out (Holland 1995:34). Folk-biological taxonomies provide both the built-in constraints and flexibility adequate for a wide range of culturally appropriate responses to various environments. By contrast, scientific taxonomies are of limited value in everyday life, and some of the knowledge they elicit (e.g., that tree, bird, sparrow and worm are not valid taxa) may be inappropriate to a wide range of a person's life circumstances.

Concerning competition among theories, even in our own culture such competition only marginally affects the folk-biological core (Dupreegrave; 1981, Atran 1987b). A tendency towards cultural conservatism and convergence in folk biology may be a naturally selected aspect of the functioning of the folk-biology module. As in the case of language, the syntactic structure is geared to generate fairly rapid and comprehensive semantic agreement, which would likely have been crucial to group survival (Pinker & Bloom 1990).[16] Fundamental conflicts over the meaning or extension of tree, lion and deer would hardly have encouraged cooperative subsistence behavior.

All scientific theories may be characterized, in principle, in relation to their competition with other theories (Popper 1972, Lakatos 1978, Hull 1988). An intended goal of this competition is to expand the database through better organizing principles. This is the minimum condition for the accumulation of knowledge that distinguishes science as a Western tradition from other cultural traditions. For example, it is only in Europe that a cumulative development of naturally history occurred that could lead to anything like a science of biology. Thus, the Chinese, Ottoman, Inca and Aztec empires spanned many local folk-biological systems. Unlike Europe, however, these empires never managed to unite the species of different folk-biological systems into a single classification scheme, much less into anything like a unified causal framework (Atran 1990).

Finally, consider that a penchant for calling intuitive data-organizing principles "theories" may stem, in part, from a peculiar bias in analytic philosophy and cognitive psychology. This bias consists in using the emergence of scientific knowledge as the standard by which to evaluate the formation of ordinary knowledge about the everyday world. From an anthropological vantage, this is peculiar because it takes as a model of human thought a rather small, specialized and marginal subset of contemporary thought. It is rather like taking the peculiar knowledge system of another cultural tradition, such as Maya cosmography, and using this to model human thought in general.

This bias to model human cognition on scientific thought is historically rooted in the tradition of Anglo-American empiricism, which maintains that science is continuous with common sense, both ontologically (Russell 1948) and methodologically (Quine 1969). It is supposedly a natural and more perfect extension of common sense that purges the latter of its egocentric and contextual biases: for, "it is the essence of a scientific account of the world to reduce to a minimum the egocentric bias in [an everyday] assertion" (Russell 1957:386). When faced with a choice between commonsense kinds and scientific kinds whose referents substantially overlap, people ought to pick the scientific kind; for, "we should not treat scientists' criteria as governing a word which has different application-conditions from the 'ordinary' word" (Putnam 1986:498; cf. Kripke 1972:315).

The belief that folk taxonomies are approximations to scientific classifications confounds two appropriate empirical observations and one inappropriate metaphysical supposition. The observations are that: the terms for commonsense generic species and the species terms used in science are often the same; and scientific classification did initially stem from commonsense classification. The erroneous supposition is that both terms denote "natural kinds," and that people will refine their use of natural-kind terms as science improves because this is an inherent part of understanding what they "mean." This entails that there is no a priori mental ("syntactic") constraint on our use or understanding of biological kinds. There is only a semantic understanding that is determined a posteriori by scientific discoveries about the correct or true structure of the world. In fact, neither the terms for generic species nor the species terms used in science denote natural kinds. Consider:

Mill (1843), who was one of Russell's mentors, introduced the notion of natural kind in the philosophy of science. Natural kinds were to be nature's own "limited varieties," and would correspond to the predicates of scientific laws in what was then thought to be a determinate Newtonian universe. Counted among the fundamental ontological kinds of this universe were biological species and the basic elements of inert substance (e.g., gold, lead).[17]

In evolutionary theory, however, species are not natural kinds. "Speciation," that is the splitting over time of more or less reproductively isolated groups, has no fixed beginning and can only be judged to have occurred to some degree through hindsight. No hard and fast rule can distinguish a variety or genus from a species in time, although failure to interbreed is a good rule of thumb for distinguishing (some) groups of organisms living in close proximity. No laws of molecular or genetic biology consistently apply to all and only species. Nor is there evidence for a systematic deferral to science in matters of everyday biological kinds. This is because the relevance of biological kinds to folk in everyday life pertains to their role in making the everyday world comprehensible, not in making the cosmos at large transparent. When folk assimilate some rather superficial scientific refinements to gain a bit of new knowledge (e.g., whales and bats), these usually affect the antecedent folk system only at the margins.

In sum, a "scientific" notion of the species as a natural kind is not the ultimate reference for the commonsense meaning of living kind terms. There is marked discontinuity between evolutionary and preevolutionary conceptions of species. Indeed, the correct scenario might be just the reverse. A notion of the species as a natural kind lingers in the philosophy of science and resolutely persists in psychology (Schwartz 1979, Rey 1983, Carey 1985, Gelman 1988, Keil 1995), which indicates that certain basic notions in science are as much hostage to the dictates of common sense as the other way around. So, to the questions - "what, if not natural kinds, are generic species?" and "what, if not a theory, are the principles of folk biology ?" - the answer may be simply "they are what they are." This is a good prospect for empirical research

CONCLUSION

The uniform structure of taxonomic knowledge, under diverse socio-cultural learning conditions, arguably results from domain-specific cognitive processes that are panhuman, although circumstances trigger and condition the stable structure acquired. No other cognitive domain is invariably partitioned into foundational kinds that are so patently clear and distinct. Neither does any other domain so systematically involve a further ranking of kinds into inductively sound taxonomies, which express natural relationships that support indefinitely many inferences.

Although accounts of actual causal mechanisms and relations among taxa vary across cultures, abstract taxonomic structure is universal and actual taxonomies are often recognizably ancient and stable. This suggests that such taxonomies are products of an autonomous, natural classification scheme of the human mind, which does not depend directly on an elaborated formal or folk theory. Such taxonomies plausibly represent "modular" habits of the mind, naturally selected to capture recurrent habits of the world relevant to hominid survival in ancestral environments. Once emitted in a cultural environment, the ideas developed within this universal framework spread rapidly and enduringly through a population of minds without institutionalized instruction. They tend to be inordinately stable within a culture, and remain by and large structurally isomorphic across cultures.

Within this universal framework people develop more variable and specific causal schema for knowing taxa and linking them together. This enables people to interpret and anticipate future events in their environments in locally relevant ways. To be sure, there are universal presumptions that species-like kinds have underlying causal natures, and this drives learning. As a result, people across the world teleologically relate observable morphology, internally directed growth and transgenerational inheritance to developing ideas about the causal constitution of generic species. But no culturally elaborated theory of life's integral properties need causally unite and differentiate all such kinds by systematic degrees.

Thus, it is not the cultural elaboration of a theory of biological causality that originally distinguishes people's understanding of the species concept, taxonomy and teleology, as these apply to (nonhuman) animals and plants from understanding basic concepts and organization of inert substances, artifacts or persons. Rather, the spontaneous arrangement of living things into taxonomies of essential kinds constitutes a prior set of constraints on any and all possible theories about the causal relations between living kinds and their biological properties. This includes evolutionary theories, such as Darwin's, which ultimately counter this commonsense conception.

From a scientific standpoint, folk-biological concepts such as the generic species are woefully inadequate for capturing the evolutionary relationships of species over vast dimensions of time and space - dimensions that human minds were not directly designed (naturally selected) to comprehend. All taxa are but individual segments of a genealogical tree (Ghiselin 1981), whose branchings may never be clearcut. Only by laborious cultural strategies like those involved in science can minds accumulate the knowledge to transcend the bounds of their phenomenal world and grasp nature's subtleties. But this requires continued access to the intuitive categories that anchor speculation and allow more sophisticated knowledge to emerge, much as the universal intuition of solid bodies and contingent movement has anchored scientific speculation about mass, matter and motion.

This does not mean that folk taxonomy is more or less preferable to the inferential understanding that links and perhaps ultimately dissolves taxa into biological theories. This "commonsense" biology may just have different conditions of relevance than scientific biology: the one, providing enough built-in structural constraint and flexibility to allow individuals and cultures to maximize inductive potential relative to the widest possible range of everyday human interests in the biological world; and the other, providing new and various ways of transcending those interests in order to infer the structure of nature in itself, or at least a nature where humans are only incidental. Because common sense operates unaware of its limits, whereas science evolves in different directions and at different rates to surpass those limits, the boundary between them is not apparent. A research task of "the anthropology of science" is to comprehend this division of cognitive labor between science and common sense: to find the bounds within which reality meets the eye, and to show us where visibility no longer holds the promise of truth.

NOTES

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Footnotes

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[2] Thus, comparing constellations in the cosmologies of Ancient China, Greece and the Aztec Empire shows little commonality. By contrast, herbals like the Ancient Chinese ERH YA, Theophrastus's Peri Puton Istorias, and the Aztec Badianus Codex, share important features, such as the classification of generic species into tree and herb life forms (Atran 1990:276).

[3] By contrast, a partitioning of artifacts (including those of organic origin, such as foods) is neither mutually exclusive nor composed of inherent natures: some mugs may or may not be cups; an avocado may be a fruit or vegetable depending on how it is served; a given object may be a bar stool or waste bin depending on the social context or perceptual orientation of its user; and so on.

[4]4. It makes no difference whether these groups are named. English speakers ambiguously use "animal" to refer to at least three distinct classes of living things: nonhuman animals, animals including humans, and mammals (the prototypical animals). The term "beast" seems to pick out nonhuman animals in English, but is seldom used today. "Plant" is ambiguously used to refer to the plant kingdom, or to members of that kingdom that are not trees.

[5]5. Life forms vary across cultures. Ancient Hebrew or modern Rangi (Tanzania) include herpetofauna (reptiles and amphibians) with insects, worms and other "creeping crawlers" (Kesby 1979), whereas Itzaj Maya and (until recently) most Western cultures, include herpetofauna with mammals as "quadrupeds." Itzaj place phenomenally isolated mammals like the bat with birds, just as Rofaifo (New Guinea) place phenomenally isolated birds like cassowaries with mammals (Dwyer 1976). Whatever the content of life-form taxa, the life-form level, or rank, universally partitions the living world into broadly equivalent divisions.

[6]6. In the logical structure of folk taxonomy, outliers may be considered monotypic life forms with only one generic species (for a formalism, see the appendix in Atran 1995).

[7]7. Botanists and ethnobotanists tend to see preferred folk-biological groups as akin to scientific genera (Bartlett 1940, Berlin, 1972, Greene 1983). Plant genera especially are often groups most easily recognized morphologically without technical aids (Linnaeus 1751). Zoologists and ethnozoologists tend to view them as more like scientific species, where reproductive and geographical isolation are more readily identified in terms of behavior (Simpson 1961, Diamond 1966, Bulmer 1970).

[8] In a comparative study of Itzaj Maya and rural Michigan college students, we found that the great majority of mammal taxa in both cultures correspond to scientific species, and most also correspond to

monospecific genera: 30 of 40 (75%) basic Michigan mammal terms denote biological species, of which 21 (70%, or 53% of the total) are monospecific genera; 36 of 42 (86%) basic Itzaj mammal terms denote biological species, of which 25 (69%, or 60% of the total) are monospecific genera (Atran 1995, Lûpez et al. 1997). Studies of trees in both the Peten rainforest and Chicago area reveal a similar pattern (Atran 1993; Medin et al. 1997).

[9] Moving vertically within each graph corresponds to changing the premise while holding the conclusion category constant. This allows us to test another domain-general model of category-based reasoning: The Similarity-Coverage Model (Osherson et al. 1990). According to this model, the closer the premise category is to the conclusion category, the stronger the induction should be. Our results show only weak evidence for this general reasoning heuristic, which fails to account for the various "jumps" in inductive strength that indicate absolute or relative preference (Atran et al. in press). Note also that we conducted separate experiments to control for the effects of linguistic transparency; for example, whether relations between generic species and life forms were marked (e.g., catfish - fish) or unmarked (e.g., bass - fish) had no effect on results (Coley, Medin & Atran in press).

[10] The existence of universal, domain-specific cognitions is not tied exclusively, or even necessarily, to cross-cultural pervasiveness. The social subordination of women, for example, appears in all known cultures (i.e., it is a cultural "universal" in the sense of Lèvi-Strauss 1969). It could even be argued that this universal has some biological grounding. There is no reason, however, to attribute the varied ways people process this pervasive social phenomenon to a universal cognitive mechanism. Conversely, the ability to understand and develop mathematics may be rooted in some fairly specific cognitive mechanisms, with which humans are innately endowed (Gelman 1990). But if so, many cultures do not require that people use this ability. Nor is it occasioned by every environment.

[11] Each group was tested in its native language (Itzaj and English), and included a minimum of 6 men and 6 women on each task. The choice of groups of 12 or more people is based on pilot studies that indicate this is sufficient to establish a cultural consensus (Atran 1994). No statistically significant differences between men and women were found on the tasks reported. The method of successive pile sorts and taxonomic comparison was pioneered by Boster and his colleagues (Boster, Berlin & O'Neill 1986; Boster 1991).

[12] For each subject, we have a square symmetric data matrix, with the number of rows and columns equal to the number of generic species sorted. Subjects' taxonomic distance matrices were correlated with each other, yielding a pairwise subject-by-subject correlation matrix representing the degree to which each subject's taxonomy agreed with each other subject's taxonomy. Principal component factor analyses were then performed on the intersubject correlation matrix for each group of informants to determine whether or not there was a "cultural consensus" in informant responses. A cultural consensus is plausible if the factor analysis results in a single factor solution. If a single dimension underlies patterns of agreement within a domain, then consensus can be assumed for that domain and the dimension can be thought of as reflecting the degree to which each subject shares in the consensual knowledge (Romney, Batchelder & Weller 1986). Consensus is indicated by a strong single factor solution in which: (1) the first latent root (eigenvalue) is large compared to the rest, (2) all scores on the first factor are positive, and (3) the first factor accounts for most of the variance. To the extent that some individuals agree more often with the consensus than others, they are considered more "culturally competent" with respect to the domain in question. An estimate of individual knowledge levels, or competencies, is given by each subject's first factor scores. This represents the degree to which that subject's responses agree with the consensus. That is, the pattern of correlations among informants should be based entirely on the extent to which each subject knows the common (culturally relative) "truth." The mean of all first-factor scores provides an overall measure of consensus.

[13] Different types of "scientific taxonomy" correlate differently with folk taxonomy, with cladistic taxonomies (based on strict phylogentic branching) generally being the least correlated and phenetic taxonomies (based on relations among observable characters) being the most. Evolutionary taxonomies represent a compromise of sorts between cladistics and phenetics.

[14] Apparent lack of taxonomically based diversity is not limited to Itzaj reasoning about mammals (they show the same pattern when reasoning about birds and palms, Atran in press), nor is it limited to nonwestern populations. In another series of studies exploring the impact of different kinds of expertise on categorization and reasoning about trees (Medin et al. 1997), we have found that parks and forestry maintenance workers responded significantly below chance on diversity items (Coley, Medin, Proffitt, Lynch, Coley & Atran in press). As with the Itzaj, justifications focused on ecological factors (e.g. distribution, susceptibility to disease) and associated causal reasoning. Another American group, consisting of taxonomists, sorted and reasoned in accordance with scientific classification. These results confirm the scientific reasoning patterns that were only inferred from the scientific classification in the mammal studies. Like American students on the mammal task, the taxonomists also had overwhlemingly positive responses on the diversity task. Differences in education did not appear to be significantly correlated with diversity or lack of diversity in the American populations (note also that Lopez et al. 1992 found diversity with American ten-year-olds).

[15] The situation is arguably similar for naive physics, not only between cultures, but within our own culture. DiSessa (1988) speaks of a "knowledge in pieces" involving concept clusters that reinforce and help to interpret one another in order to guide people's uninstructed expectations and explanations about many situations of potential relevance to them. Although there is appreciable diversity of expectations and explanations, there are strong tendencies towards the convergence of concept clusters across individuals (and presumably across cultures). These are fairly robust, even for people with formal or scientific education, in part because there is substantial overlap between scientific (Newtonian) and commonsense physics. The causal clusters that are formed, however, reflect local family relationships rather than global coverage: "The impetus theory is, at best, about tosses and similar phenomena. It does not explain how people think about objects on tables, or balance scales, or orbits" (diSessa 1996:714).

[16] There is also the cryptic notion of "tacit theory" that originally came from Chomskian linguistics. Generative linguists rightly seem to consider this more of a throwaway notion than do some philosophers. Using "tacit theory" to assimilate universal grammar and universal taxonomy would wrongly entail assimilating a core module to an input module, and perhaps also to any complex biological algorithm (instinct) or automatic organizing process.

[17] Aristotle first proposed that both living and inert kinds had essential natures. Locke (1848/1689) dubbed these unknowable kinds, "real kinds," claiming that their underlying natures could never be wholly fathomed by the mind. Across cultures, it is not clear that inert substances comprise a cognitive domain that is conceived in terms of underlying essences or natures. Nor it is obvious what the basic elements might be, since the Greek earth, air, fire and water are not universal. The conception of "natural kind," which supposedly spans all sorts of lawful natural phenomena, may turn out not to be a psychologically real predicate of ordinary thinking (i.e., a "natural kind" of cognitive science). It may be simply an epistemic notion peculiar to a growth stage in Western science and philosophy of science.
