

Knowledge and Category-Based Induction¹

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In this chapter we will present findings from a program of research—conducted both inside and outside the lab—aimed at discovering how real-world knowledge impacts the use of categories in inductive reasoning. To preview, we will argue that the specific effects of knowledge on category-based induction include rendering non-taxonomic relations (including causal, ecological and thematic relations) available for guiding inferences, and increasing their salience relative to taxonomic relations. This in turn has the effect of increasing the flexibility with which knowledgeable individuals can access and utilize different relations to guide induction in response to the specifics of the context. However, these changes come with an additional processing burden in that it is more time consuming to utilize specific relational knowledge than to rely on general similarity. Taken together, these findings demonstrate that in order to develop adequate accounts of how concepts are used in reasoning, we must consider the impact of knowledge and experience on this process.

Background

The research described herein focuses on category-based induction, defined for present purposes as the process by which we project knowledge about certain classes of entities to other related classes of entities. For example, given that *mice have ilia*, inferring that *rats have ilia*, or that *all rodents have ilia*, or that *cats have ilia* would be an inductive inference. Generally speaking, the likelihood of an inductive inference is a function of the relevant relations believed to exist among the classes involved. But given the myriad relations which exist among classes of entities, which relations do we rely on to guide inductive inferences, and why?

Most current accounts of category-based induction emphasize the importance of taxonomic relations in guiding reasoning (e.g., Osherson, Smith, Wilkie, Lopez & Shafir, 1990; Rips, 1975; Sloman, 1993; see Heit, 2000 for a review). Taxonomic relations among concepts are based on global or specific similarity, shared features, or class inclusion. The Similarity Coverage Model (Osherson et al, 1990) has been particularly influential. According to this model, inductive arguments are perceived as strong to the extent that (1) premise categories are deemed similar to conclusion categories, and (2) premise categories are deemed similar to sampled instances of a superordinate category including both premise and conclusion. This second principle, known as coverage, predicts a phenomenon known as premise diversity, whereby arguments with

¹ In Ahn, W., Goldstone, R. L., Love, B. C., Markman, A. B., & Wolff, P. (Eds.) (2005), *Categorization inside and outside the laboratory: Essays in honor of Douglas L. Medin*. Washington, DC: American Psychological Association. We thank Doug Medin for the inspiration, and Tara Kane, Carissa Kemp, Rachel Kolter, Adam Nicolazzo, Finessa Slater, Marta Ullrich, and Aixa Martinez Zuviría for the perspiration. We also thank Phil Wolff for very helpful comments on the chapter.

dissimilar premises are deemed stronger than arguments with similar premises, all else being equal. For example, compare the following arguments:

- (a) *Sparrows* have ilia.
Cats have ilia.
All animals have ilia.
- (b) *Sparrows* have ilia.
Blue jays have ilia.
All animals have ilia.

The SCM predicts that (a) will be seen as stronger than (b) because sparrows and cats--relatively dissimilar animals--“cover” the category animal more completely (i.e., are similar to more kinds of animals) than sparrows and blue jays, which are relatively similar to each other, and thus provide less complete coverage of animal. More generally, the SCM predicts that inductive inferences will be strong to the degree that premise and conclusion categories are similar, and/or premise categories provide adequate coverage of conclusion categories. Another model of induction based on taxonomic relations is the Feature-Based Induction Model (Sloman, 1993). In brief, this model posits that vectors of features representing concepts are compared to each other, and inferences are strong to the degree that premise and conclusion concepts share features. Although this model differs from the SCM in important ways, for present purposes both models are driven by the idea that inductive inferences are based largely on taxonomic relations between concepts. Both models do an excellent job of predicting how US college undergraduates evaluate the relative strength of inductive arguments.

However, models based solely on taxonomic relations do not fare so well in predicting how experts reason in their domain of expertise; relative experts rely on causal or ecological relations as well as taxonomic relations in both categorization and reasoning. For instance, Lopez, Atran, Coley, Medin and Smith (1997) compared categorization and reasoning about local mammal species by the Itza' Maya of lowland Guatemala and US undergraduates from the University of Michigan. The Itza' depend on local plants and animals for subsistence, and have extensive folk knowledge of local species. The undergraduates possessed much less expertise about local species. Lopez et al. (1997) compared diversity-based reasoning in these two populations by presenting paired premises and asking which premise provided better evidence for an inference to a general conclusion category. For the diversity items, one premise pair contained two relatively dissimilar species (i.e., the choice predicted to be stronger via diversity) and the other contained two similar species (the non-diverse choice); the conclusion category was "all mammals around here." A measure of similarity among species was derived from results of a card-sorting task performed in each locale. Participants were told that each pair of mammals had a different newly discovered disease, and were asked to choose which disease was more likely to effect “all mammals around here.” The U.S. undergraduates picked the more diverse premises 96% of the time, suggesting heavy reliance on taxonomic relations. In contrast, the Maya picked the more diverse pair only 38% of the time, indicating no systematic reliance on taxonomic relations. Justifications were not systematically analyzed, but suggested that ecological relations, such as habitat, range, or feeding habits, were more salient to the Itza' than taxonomic relations among species. For instance, a typical Itza' explanation might revolve around the fact that diverse species were unlikely to contract the same disease, or that taxonomically similar species actually occur in different habitats and therefore are more likely to spread a disease widely. That is, on diversity items, the Maya picked the pair for which they could make the best reason as to why

both had the novel disease. Often times, this happened to be the taxonomically less diverse pair.

To examine the source of this striking difference, Proffitt, Coley & Medin (2000) investigated diversity-based reasoning in U.S. tree experts. If US experts used diversity-based reasoning like the US undergraduates, then differences between US undergraduates and Itza' in Lopez et al. (1997) could be attributed to culture rather than experience. As in Lopez et al. (1997), US tree experts were given two pairs of local tree species. Again, based on participants own sorting of the tree species involved, one pair was similar, and one pair was dissimilar and therefore predicted to support stronger inferences via diversity. Participants were told that each pair had a new disease, and asked which disease was more likely to affect all trees. Like the Itza', US tree experts did not choose the more diverse pair significantly more than chance, suggesting that extensive domain-specific experience reduced reliance on taxonomic relations for guiding inductive inferences. Also like the Itza', US tree experts mentioned causal or ecological factors in 56% of their justifications, including distribution, disease resistance, and native versus exotic origin of tree species. This is not to say that similarity-based reasoning played no role in experts' inductive generalizations; it likely did. But clearly, in these experts' justifications, similarity took a back seat to domain specific knowledge about causal/ecological relations among concepts in explaining inductive generalizations.

In both of these studies, experts' inferences were not well-predicted by their own beliefs about general taxonomic relations among items in their domain of expertise. Rather, for both the Itza' and US tree experts, the task seemed to trigger causal/ecological reasoning. These causal relations driven by domain-specific knowledge may be thought of as thematic relations. According to Lin and Murphy (2001), "Thematic relations are the external or complementary relations among objects, events, people, and other entities that co-occur or interact together in space and time" (p. 3). Although work on conceptual development has addressed relative salience of thematic versus taxonomic relations in children (e.g., Smiley & Brown, 1979; Markman & Hutchinson, 1984; Waxman & Namy, 1997), researchers have emphasized the ascendancy of taxonomic relations. However, the findings described above--that thematic relations among concepts played a major role in guiding experts' inferences--suggest that this emphasis may not be warranted. In brief, by taking the study of category-based induction outside the laboratory, Medin and his team have shown that background knowledge strongly influences what relations are used to guide induction; in the case of experts, thematic relations seem particularly salient guides for inductive inference (see also Luria, 1976; Cole, Gay, Glick & Sharp, 1971; Sharp, Cole & Lave, 1979; Lin and Murphy, 2001; Ross & Murphy, 1999). In the following, we describe several studies which elaborate on this finding.

Inferences based on Causal Relations: Expert and Novice Reasoning about Marine Creatures

In the research reviewed above, evidence for expert use of non-taxonomic relations amounts to a failure of the predictions of taxonomic diversity coupled with careful analysis of experts' explanations for their inferences. Recent work in our lab (Shafto & Coley, 2003) using a more open-ended methodology revealed positive evidence of causal inferences among experts, and also suggests that in addition to rendering various non-taxonomic relations salient, experience may also provide greater flexibility in applying different kinds of relations in different inferential contexts. Experts (commercial fishermen) and novices (undergraduate students) were shown pairs of marine creatures and told that they shared either an undisclosed property (e.g., "these both have a property called theta") or a novel disease (e.g., "these both have a disease called theta"). Instead of deciding which pair provided better evidence for a generalization to *all sea*

creatures, participants chose which specific marine creatures from representatives of the local ecology would share the property with each premise pair, thereby permitting detailed examination of the specific relations used to guide inferences.

We predicted that novices, with relatively limited knowledge about the natural world, would project both kinds of properties along taxonomic lines. Experts, however, should use information in the properties to guide their inductions, thus using taxonomic relations to generalize novel properties and causal relations to guide their generalizations of novel diseases. Results indicate that novices again relied heavily on taxonomic relations (based on previously collected sorting data) to guide inferences about both property and disease. Experts also used taxonomic relations to guide inferences about unspecified properties. In contrast, experts used causal relations—knowledge of marine food chains—to guide inferences about unfamiliar diseases. The average proportion of generalizations was the same for both novice groups and the experts who projected novel properties. However, experts in the novel disease condition generalized significantly more. Moreover, although in all conditions patterns of inferences correlated significantly with similarity ratings derived from a previous sorting task, this correlation was much weaker for experts reasoning about disease. Therefore, we selected creatures that either ate the premises (that were higher in the food chain) or were eaten by the premises (that were lower in the food chain). We compared the proportion of generalizations to these specific targets to the average proportion of generalizations to all targets in each condition. Results revealed that experts projected a novel disease to creatures higher in the food chain (i.e., creatures that habitually preyed on a diseased species) significantly more than average. No such increase in projections was observed for creatures lower in the food chain (i.e., creatures that were habitually preyed upon by a diseased species). Nor were there any such effects of food chain relations for experts when reasoning about property, or for novices reasoning about disease or property. The asymmetry of this finding strongly suggests an underlying causal belief was guiding expert inductive inferences about disease; namely, that disease can be spread by eating a diseased creature. Experts also flexibly utilized causal relations to guide inferences about disease, but not about a blank property. It seems that expertise involves knowledge of many kinds of relations among items which are selected from in a context-dependent manner. The interaction between relations and properties suggests that experts have two underlying knowledge structures. Hierarchical structures store taxonomic knowledge about the relatively context-independent similarity among items. Relational structures store causal knowledge about how the items interact in space and time. The application of these different structures is cued by an underlying theory about how particular properties relate to the domain at large and to the specific items under consideration.

Expert and Novice Reasoning about Music

In another set of studies (Baraff & Coley, 2003; Coley & Baraff, 2003), we have examined category-based induction in the domain of music. Music poses an interesting contrast to folk biology due to its abstract nature—similarity cannot be computed based on obvious visual properties or features. One goal of these studies was to assess the generalizability of novice/expert natural kind induction differences. Research reviewed above suggests that novice category-based induction is predicted by taxonomic/similarity relations. Experts, on the other hand, appear to favor both specific knowledge rendered relevant by relations among categories and properties over general taxonomic relations among categories. Thus, if results previously reported in the domain of biology are general, then, in the domain of music, experts should

flexibly use both general taxonomic/similarity relations and more specific relations rendered salient by the context of the inference. However, novices, who by definition have little detailed relational information available to them should only use taxonomic information.

To test this question, 12 novices and 12 experts were recruited to perform two tasks. Novices lacked extensive music training and/or courses in ethnomusicology. Experts were musicians or composers from the greater Boston area. In the first task, participants were asked to sort twenty-five index cards, each with a different composer's full name. Composers were chosen to be generally familiar (based on pretesting) and to represent a range of musical genres (e.g., Beethoven, Bob Dylan, Andrew Lloyd Weber). Participants were asked to sort based on similarity of music composition style. Based on the results of this sorting task, 24 inductive arguments were constructed to be used in a standard strength-of-argument rating task that assessed the degree to which measures of taxonomic distance (derived from the sorting task) would predict category-based inferences. Of these arguments, 16 consisted of diversity-based arguments, and 8 similarity-based arguments (see Osherson et al., 1990). All items contained two premises and a conclusion, and for all arguments, the property being queried was "uses technique X in music writing" where X was a different letter for each item. This property was chosen to be as blank as possible; i.e., it's unlikely that participants would have prior beliefs about whether specific composers use technique X. Sample items are presented in Table 1. In the Strong Argument column, the first argument is taxonomically strong because *Beethoven* and *Bach* are very similar to *Mozart* (based on results of the sorting task). The second argument is taxonomically strong because *Bach* and *Bob Marley* are each similar to very different composers and therefore provide strong coverage of *all composers*. In the Weak Argument column, the first argument is taxonomically weak because *Bob Marley* and *John Lennon* are not similar to *Mozart*; the second is taxonomically weak because *Beethoven* and *Bach* are very similar to each other, and therefore do not cover *all composers* very well.

Taxonomically Strong Arguments	Taxonomically Weak Arguments
<p><i>Beethoven</i> uses technique X in music writing.</p> <p><u><i>Bach</i> uses technique X in music writing.</u></p> <p><i>Mozart</i> uses technique X in music writing.</p>	<p><i>Bob Marley</i> uses technique X in music writing.</p> <p><u><i>John Lennon</i> uses technique X in music writing.</u></p> <p><i>Mozart</i> uses technique X in music writing.</p>
<p><i>Bach</i> uses technique X in music writing.</p> <p><u><i>Bob Marley</i> uses technique X in music writing.</u></p> <p><i>All composers</i> use technique X in music writing.</p>	<p><i>Beethoven</i> uses technique X in music writing.</p> <p><u><i>Bach</i> uses technique X in music writing.</u></p> <p><i>All composers</i> use technique X in music writing.</p>

Table 1. Sample Items from Music Strength-of-Argument Rating Task.

Arguments were presented via computer. Each argument was initially presented in red lettering for 15 seconds during which no response could be entered; after the 15-second interval, the lettering turned green indicating that the participant could now input their response. Instructions encouraged participants to take their time and think about each question carefully before answering. Participants rated the strength of each argument individually, on a scale of 1 (weak argument) to 7 (strong argument). Additionally, response times were recorded from the point at which the lettering turned green to the point at which a response was entered. Twelve novices (all lacking any extensive music training and/or coursework in music) and 11 experts (musicians and composers from the greater Boston area) were run.

If novices rely on taxonomic relationships, they should rate strong arguments to be significantly stronger than weaker arguments. If experts rely on specific knowledge of composers rather than general taxonomic relations, they should not necessarily rate taxonomically strong or weak arguments differently. As predicted, novices rated arguments predicted to be taxonomically strong ($M=4.45$) significantly higher than arguments predicted to be taxonomically weak ($M=2.80$). In contrast, there was no difference between expert ratings of strong and weak arguments ($M=4.18$ and 3.53 , respectively). Results were precisely as previously reported for folk biology; novice responses reflected their taxonomic sorts, whereas experts resorted to another strategy to rate argument strength. While it is not clear specifically what type of reasoning experts abandoned taxonomic-based responses for, it is likely that their responses are contingent on the specific knowledge and beliefs about the composers mentioned in each argument. For example, one expert explained informally that Mozart and Bon Jovi--a diverse premise pair predicted to have relatively high coverage based on sorting data--were actually quite similar in that both use strong beats in their composition style. Likewise, this expert pointed out that Mozart and Debussy--both from the *classical* group and therefore predicted to have relatively low coverage--were actually quite different as Debussy's use of free-from rhythm contrasts sharply with Mozart's use of a strong beat. Thus, this expert demonstrated use of diversity, but responded based on context-dependent relational knowledge instead of general taxonomic/similarity-based knowledge demonstrated in the initial sorting task. In contrast, novices, lacking such detailed specific knowledge, rely on the taxonomic relations revealed by their sorting. One bit of evidence in support of this explanation is the fact that experts took significantly longer than novices to respond, suggesting the use of rich, context dependent relations, which are more cognitively taxing than novice taxonomic relations.

Indeed, a second goal of these experiments was to explore this possible cognitive processing difference between taxonomic/similarity-based reasoning and context-dependent relational reasoning by testing novices and experts under time pressure. One possibility is that the context-dependent reasoning favored by experts is cognitively more demanding than similarity-based reasoning because context-dependent responses require that specific knowledge-driven relational similarity is constructed on the fly. Spontaneously generating these specific relations should be more cognitively demanding than simply accessing general taxonomic/similarity relations that are already available. Another possibility is that both context-dependent and similarity-based relations are equally cognitive taxing, either because both are generated on the fly, or because both sets of relations are already available. In this case, a cognitive load should affect both taxonomic/similarity-based responses as demonstrated by novices and context-dependent responses as demonstrated by experts.

To test this prediction, we used the same 24 inductive arguments and strength-of-argument rating

task. There were two minor changes added to induce time pressure. In the *Speeded* condition, each argument was initially presented in red lettering; however instead of a mandatory 15-second waiting time, the lettering turned green after only 3 seconds, indicating that a response could be entered. In addition, instructions encouraged participants to answer as quickly as possible without sacrificing accuracy. Twelve novices (all lacking any extensive music training and/or coursework in music) and 11 experts (musicians and composers from the greater Boston area) who had not been run in the previous studies were tested. Response time was recorded as described for the unspeded condition.

In the *speeded* condition, novices again showed a significant use of taxonomic similarity by rating arguments predicted to be taxonomically strong ($M=4.02$) significantly higher than arguments predicted to be taxonomically weak ($M=3.00$). In contrast to the *unspeded* condition, experts in the *speeded* condition also showed reliable usage of taxonomic similarity; experts rated taxonomically strong arguments ($M=4.24$) significantly higher than taxonomically weak arguments ($M=3.02$).

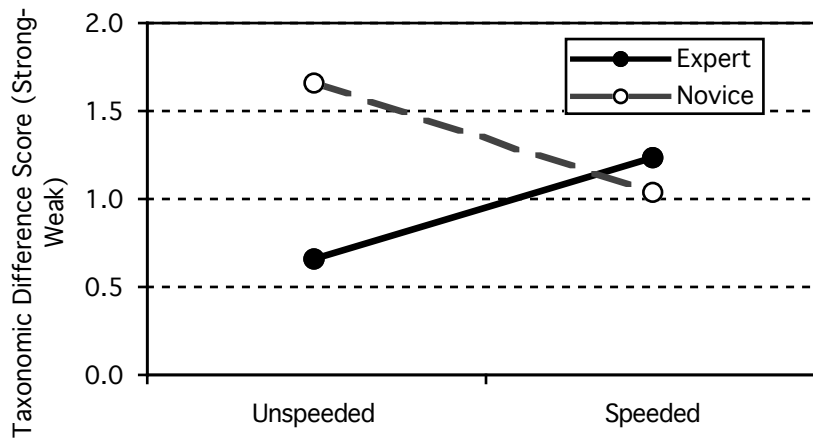


Figure 1. Effects of Time Pressure on Taxonomic Reasoning

It's critical to note that time pressure had differing effects on experts and novices. To more directly examine this interaction, we computed the difference between ratings for taxonomically strong and weak arguments. Larger differences reflect stronger accord with taxonomic predictions. Under time pressure, novices showed decreasing (albeit not significantly) differentiation of taxonomically strong

versus weak arguments, whereas experts showed significantly increasing differentiation (see figure 1). Thus, speeding up judgments did not simply introduce more variability into responses across the board. Rather, it led to a qualitative change in expert responding, but no substantive change in novice responding.

One possible account of this qualitative change in expert responses is that experts retain a general scheme of taxonomic relations among concepts in their domain of expertise, but also acquire a rich network of specific relations, which augment and potentially override general taxonomic relations in guiding inferences. In the unspeded conditions, experts had time to access these rich specific relations, and therefore their ratings were not predicted by general taxonomic similarity. In contrast, when under time pressure, rich, context-dependent relations could not be accessed quickly enough, and so experts utilized more readily available general taxonomic knowledge to guide inferences. As a consequence, expert responses showed high agreement with taxonomic sorts derived from the sorting data in the speeded conditions only. (In support of this interpretation, no differences were observed between expert and novice response time in the speeded condition.) In both conditions novices utilize general taxonomic relations as

a default approach because those are the only relations salient to them. These results suggest that category based induction utilizing rich specific context-dependent relations is cognitively more taxing than utilizing general taxonomic or similarity relations, which appear to be more available to both experts and novices under time pressure. In other words, time pressure induced a qualitative change in experts' approach to induction. In contrast, no such change was evident for novices.

The results also suggest that patterns of reasoning previously reported for folk biological induction may be more generally applicable. Without a time constraint, novice responses were predicted by taxonomic/similarity relations, whereas experts flexibly use both similarity-based and context-dependant relations to guide induction. This pattern of results mirrors inductive inference differences found between experts and novices in the domain of biology.

Domain-Specific Effects of Knowledge: Reasoning about Animals and Alcohol

Results reviewed above show that, relative to novices, experts in a given domain show decreased reliance on taxonomic relations to guide inferences and a corresponding increased use of causal or other contextual relations. Experts are also more likely to provide causal explanations of their inferences, and show greater sensitivity to the property being projected than novices. However, in all of the studies reviewed above, experts and novices were drawn from different populations (commercial fishermen, professional musicians, Itza' Maya versus university undergraduates), which introduces numerous confounds such as age, level of education, SES, etc. into the comparison. Many of these limitations were addressed in another line of study. Stepanova & Coley (2003) investigated the role of experience in category based induction by holding the population constant and manipulating the familiarity of the domain of inference. Specifically, we examine how university undergraduates reason about animals and alcoholic beverages.

We chose the domain of alcoholic beverages because (1) taxonomic relations within the domain were deemed transparent (e.g., *beer*, *wine*, *liquor*, and varieties thereof), and (2) university undergraduates are likely to be relatively experienced with alcohol. Consumption of alcohol is an integral part of college culture and drinking is an activity that most students participate in and discuss regularly. Therefore, even those students who do not drink much are still very familiar with the effects of alcohol. This extensive knowledge is abundant with various folk theories on how to maximize or minimize the effect of various types of alcohol when consumed separately or combined. Thus, college students' knowledge of alcohol may share important components with commercial fishermen's knowledge of marine creatures or the Itza' Maya's knowledge of mammals: high relevance, important part of culture, first-hand and "hands-on" experience, frequent exposure, and abundant folk theories. As such, non-taxonomic relations (such as knowledge-driven causal relations) may outweigh taxonomic relations in undergraduates' reasoning about alcohol. Reasoning about alcohol was compared to reasoning about animals. The typical undergraduate student has little direct interaction with animals, and knowledge about animals can be seen as less relevant than knowledge about alcohol. Previous studies have shown that college undergraduate's reasoning in this domain is strongly influenced by taxonomic relations among categories, such as *mammals*, *birds* and *fish*. In general, we predicted that undergraduate reasoning about alcohol should show features of an expert reasoning profile (fewer consistent diversity-based choices; more causal explanations of choices, more sensitivity to property) whereas undergraduates reasoning about animals should show a novice reasoning profile (more consistent diversity-based choices; more taxonomic explanations of choices, little sensitivity to property).

Stimuli used in the domain of alcohol were categorical arguments employing specific kinds of beer (e.g., *Samuel Adams*), wine (e.g., *merlot*) and/or hard liquor (e.g., *Absolut vodka*) as premises. Three pairs of arguments were chosen to test premise diversity; in each pair, the strong argument contained premises from two categories of alcohol whereas the weak argument contained two premises from the same category. The conclusion for these three pairs was general (*any alcohol*). Nine additional arguments were included in the task as distractors that will not be discussed here. Analogous items were constructed for the domain of animals, but instead of beer, wine and liquor they employed specific kinds of mammals (e.g. *skunk*), birds (e.g. *robin*) and fish (e.g. *salmon*). See Table 2 for sample items.

Domain	Taxonomically Strong Arguments	Taxonomically Weak Arguments
Alcohol	Samuel Adams Beer	Samuel Adams Beer
	<u>Absolute Vodka</u>	<u>Rolling Rock Beer</u>
	Any alcohol	Any alcohol
Animals	Skunk	Skunk
	<u>Salmon</u>	<u>Coyote</u>
	Any animal	Any animal

Table 2. Sample Items from Animals/Alcohol Strength-of-Argument Rating Task.

Participants were asked two kinds of questions in each domain. In the domain of alcohol, participants were asked to generalize a novel chemical property or the propensity of different alcoholic beverages to induce sickness. In the domain of animals, participants were asked to generalize a novel chemical property or the propensity of a given food to make different animals sick. In the unfamiliar domain of animals, we predicted that participants would rely on taxonomic-based reasoning strategies to generalize both properties. In the more familiar domain of alcohol, we predicted that participants would modulate their reasoning strategy depending on the property. The less familiar *chemical* property was expected to lead to taxonomic-based reasoning; the more familiar *getting sick* property was expected to lead to more causal reasoning because of its relevance to students’ beliefs and theories about alcohol.

Potential inferences were presented as a force choice; items were presented in randomize order; and participants were asked to explain each choice. 186 undergraduate participants were randomly assigned to one of four conditions (presented along with an example item):

Alcohol /Chemical: *Budweiser beer & Chardonnay wine contain chemical A; Budweiser beer*

and Sam Adams beer contain chemical B. Which chemical is more likely to be present in any alcohol?

Alcohol /Get Sick: Person A got sick after drinking Budweiser beer & Chardonnay wine. Person B got sick after drinking Budweiser beer and Sam Adams beer. Which person is more likely to get sick after drinking any alcohol?

Animal /Chemical: Skunk & Salmon have chemical A; Skunk & Coyote have chemical B. Which chemical is more likely to be in all animals?

Animal /Get Sick: Skunk & Salmon got sick from food A; Skunk & Coyote got sick from food B. Which food is more likely to make all animals sick?

The dependent variables of interest were (1) consistent diversity-based choices (percentage of participants who chose 2 or more diversity arguments out of three), and (2) consistent taxonomic or causal explanations of choices (percentage of participants who explained two or more out of three choices with taxonomic or causal justifications). Explanations were coded as *taxonomic* (mentioning similarity among categories or coverage of superordinate, e.g. explaining a choice of beer and bourbon “Because he got sick from a wider variety of alcohol”) or *causal* (specifying a process or mechanism using vocabularies not present in the event descriptions, e.g. explaining the same choice of beer and bourbon “ Because if they throw up off beer, they are more likely to throw up off anything; beer is lighter than vodka”). Three or four out of four independent coders agreed on 90% of all justifications, remaining disagreements were resolved by discussion.

Diversity-based choices. As predicted, property had an effect on consistent diversity choices in the *alcohol* domain but not in the *animal* domain. Specifically, in the alcohol domain, more participants consistently chose diverse arguments when reasoning about getting sick than when reasoning about a chemical. In the animal domain, property had no effect on consistent diversity choices (See figure 2). However, there was no difference between domains in the number of

participants who were consistent in their diversity-based choices (alcohol: 77%; animals: 75%).

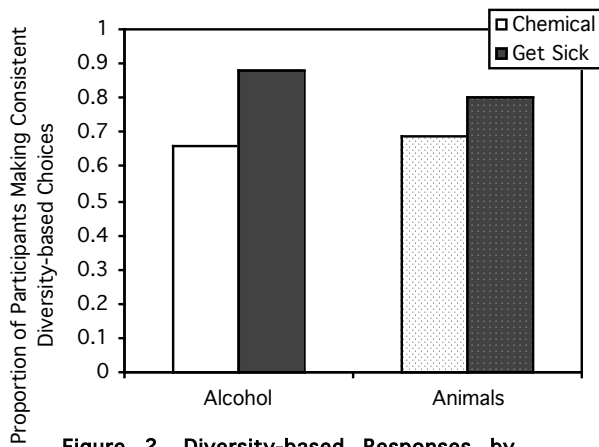


Figure 2. Diversity-based Responses by Domain and Property

Explanations. As with diversity-based inferences, property had the predicted effect on both taxonomic and causal justifications in the *alcohol* domain but not in the *animal* domain (see Figure 3). Specifically, in the alcohol domain, taxonomic explanations were more common for inferences about a chemical, whereas causal explanations were more common for inferences about getting sick. In the animal domain, property had no effect on explanations provided for inferences.

Similarly to diversity-choice results, the number of participants consistently providing taxonomic or causal explanations did not differ between domains (taxonomic explanations: alcohol 78%; animals 74%; causal explanations: alcohol 22%, animals 26%).

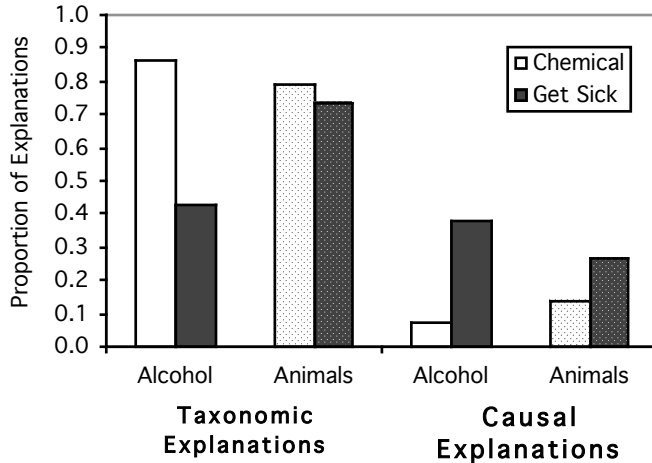


Figure 3. Explanations by Domain and Property

The results of the domain manipulation show that experience does not lead to a global change in reasoning. Undergraduates reasoning about alcohol did not differ from undergraduates reasoning about animals in terms of overall consistent diversity-based choices or the nature of their explanations. This suggests that fundamentally these two domains are not as different as they seem, their taxonomic structure is not incomparable and our manipulation of experience by

varying domain is not confounded by structural differences between these two domains.

The critical result of this set of studies is that the role of property in inductions and explanations varies depending on the domain and experience associated with it. Undergraduates showed ubiquitous property effects when reasoning about alcohol, and no such effects when reasoning about animals. When reasoning about alcohol, undergraduates made more consistent diversity-based choices when drawing inferences about *getting sick* than when drawing inferences about a *chemical*. Likewise, when reasoning about alcohol, undergraduates were more likely to provide causal explanations and less likely to provide taxonomic explanations for inferences about *getting sick* relative to inferences about a *chemical*. In contrast, when reasoning about animals, no such differences between getting sick and chemical were observed. This differential sensitivity to property is very similar to property effects found with commercial fishermen when they reasoned about the subject of their expertise – fish (Shafto & Coley, 2003).

If we consider sensitivity to specific relations rendered relevant by contextual factors—such as the property being projected—as one of the important factors that distinguish the reasoning of experts from that of novices, then we may conclude that the same population of college students showed expert-like reasoning in the domain of alcohol and novice-like reasoning in the domain of animals. Moreover, undergraduate reasoning about alcohol shows striking parallels to expert folk biological reasoning characterized by flexibility and sensitivity to context.

Towards a Comprehensive Model of Category-Based Induction

Taken together, these results suggest that when drawing inductive inferences, we use a broad array of relevant knowledge, including specific causal, and thematic relations rendered salient by the context of the inference as well as general taxonomic relations among categories. More specifically, they demonstrate several recurrent themes with respect to how knowledge informs category-based induction. First, a wide variety of conceptual relations are available to knowledgeable experts, who utilize causal, taxonomic, and other specific relations to guide inductive inference. Thus, knowledge seems to have the effect of increasing the availability of different kinds of relations to guide induction. Importantly, knowledge does not simply lead to an abandonment of taxonomic reasoning, but rather perhaps a reordering of the salience of non-taxonomic relations relative to general taxonomic similarity. In support of this, Shafto & Coley

(2003) found that experts were no less taxonomic than novices in their reasoning about “property X.” Likewise, without time pressure, music experts’ inferences were presumably guided by rich context-specific relational knowledge, but under time pressure they reasoned as predicted by general taxonomic similarity. This suggests experts preferred to use specific relational knowledge when possible, but were perfectly able to reason taxonomically when necessary.

Second, and relatedly, knowledge has the effect of increasing the flexibility with which different kinds of relations can be recruited to guide inferences. This is particularly evident in the consistent effects of property on patterns of inference for commercial fishermen reasoning about marine creatures, and for undergraduates reasoning about alcohol. In the former case, commercial fishermen utilized taxonomic relations when drawing inferences about “property X”, but shifted to food chain relations resulting in causal inferences about “disease X.” Novices showed no such shift. Likewise, undergraduates showed consistent property effects when reasoning about alcohol, but no such effects when reasoning about animals. Specifically, in the alcohol domain, participants exhibited increased reliance on diversity for choices, more frequent causal explanations and less frequent taxonomic explanations when reasoning about “getting sick” versus “chemical.” In contrast, in the animal domain, no differences between reasoning about getting sick and reasoning about a chemical were observed. These findings suggest that a critical effect of knowledge is to increase the flexibility with which various relations can be utilized to guide induction.

Finally, results suggest that the use of complex relational knowledge to guide induction comes at a processing cost. This evidence comes from the studies of music experts and novices. In the unsped condition, experts took reliably longer to respond than novices, and their responses were not predicted by their sorting of the composers. In contrast, in the speeded condition there were no differences between experts and novices with respect to response time, and both groups’ inferences were as predicted by similarity derived from their sorting. This pattern of results is consistent with the view that without time pressure, experts make on-line computations of argument strength based on relevant relations brought to mind by their specific knowledge of the composers mentioned in the premises. Under time pressure, experts may not be able to make these computations, and therefore default to the use of relatively fast general similarity. In contrast, novices have little more than this fast general similarity to begin with, and so show few effects of time pressure.

In sum, we suggest that the specific effects of knowledge on category-based induction include rendering a variety of conceptual relations available for guiding inferences, and increasing their salience relative to general taxonomic relations. This in turn has the effect of increasing the flexibility with which knowledgeable individuals can access and utilize different relations to guide induction in response to the specifics of the context. However, these changes come with an additional processing burden in that it is more time consuming to utilize specific relational knowledge than to rely on general taxonomic similarity.

Clearly, these findings are difficult to explain using a theory of category-based induction driven solely by taxonomic or similarity relations among concepts. For experts (and to a lesser degree, for novices), inductive inferences can be guided by general or specific taxonomic relations, but are also driven by causal and thematic relations that are not taxonomic at all. In light of such evidence highlighting the importance of thematic as well as taxonomic relations in guiding inductive inference, Medin, Coley, Storms and Hayes (2003) have proposed a framework theory of induction based on the idea of relevance. This view proposes that when evaluating an

inductive argument or making an inductive projection, salient relations among premise categories, or premise and conclusion categories, provide the basis for the inference. Background knowledge, including knowledge relevant to the property being projected, can influence the relative salience of potential relations (see McDonald, Samuels, & Rispoli, 1996, for an approach that is similar in spirit). Thus, a relevance-based approach allows for causal and thematic as well as taxonomic relations to enter into calculations of inductive potential.

We think this approach is the correct one. Moreover, we would argue that the findings we report raise several challenges for future research in category-based induction. First, the findings raise developmental questions about the acquisition of expertise and the way in which specific contextual relations come to augment general taxonomic relations for guiding inductive inferences. One way to address this question in the domain of folk biology is to examine how various relations guide induction among children growing up in environments that support differential levels of experience and direct interaction with plants and animals (Coley & Blaszczyk, 2003; Coley & Freeman, 2003; Ross, Medin, Coley & Atran, 2003). Such research could reveal either that relational reasoning develops in concert with taxonomic reasoning given a sufficiently rich environment, or that taxonomic reasoning is developmentally prior and provides a basis for further elaboration of the folk biological conceptual system. Another challenge is to explore the conditions under which relative novices access different kinds of relations to guide inferences. Even in the domain of folk biology, where undergraduates are notorious for their lack of knowledge, research has shown flexibility in inductive reasoning given relations that are sufficiently salient to compete with general taxonomic similarity (e.g., Heit & Rubinstein, 1994). A third challenge involves developing specific models of inductive reasoning that take into account the flexibility and context-sensitivity of knowledge-based induction. Medin et al. (2003) provide a likely framework within which such models could be developed, but models which detail how specific relations are selected, or dynamic models that could address how the acquisition of knowledge changes the system, remain to be worked out. In closing, we simply note that none of these potentially important avenues of future research would have suggested themselves had Doug Medin not had the wherewithal to begin to examine how people think about the complicated, messy, but ultimately real world outside the lab.

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