Building an Intuitive Biology:
Two Case Studies on the Development of Biological Concepts

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Abstract

Researchers are divided about when children can be credited with domain-specific causal reasoning about biology. The first paper contributes to this debate by characterizing the understanding young children have about the origins of species kind and species properties. It was found that while children can start reasoning about the origins of species kind in terms of a biological theory of inheritance as early as we tested (four years), the majority of children do not do so until the age of seven (67% percent). Concerning species properties, children were found to reason in terms of inheritance even later. Only 38% of seven-year-olds showed evidence of a domain-specific biological theory of property origins. Nearly half of all the children tested showed evidence of a non-domain-specific essentialist theory. While the knowledge of most of the children tested could not be characterized as causal reasoning in the domain of biology, they were above chance at all ages in the ability to predict an animal's species kind based on information about the animal's birth. This suggests that children accumulate factual knowledge about the phenomena in a domain, before they construct a causal explanatory theory.

The second paper explores this distinction between factual knowledge and explanatory knowledge in people with Williams syndrome, a rare neurodevelopmental disorder resulting in mental retardation. The paper uses existing theoretical analyses of the development of many biological concepts analogous to the one described in the first paper to diagnose subjects' construction of the adult biological concepts. It is shown that people with Williams syndrome are severely impaired in their ability to construct adult biological concepts if those concepts are incommensurable with the earliest child's concept, such as *alive, death, people-as-one-animal-*

among-many, living thing, and species kind. This is despite the fact that the same subjects demonstrate good productive, factual knowledge about animals. It is concluded that learning processes leading to the accumulation of productive, factual knowledge are distinct from processes of conceptual change involving incommensurabilites such as those involved in the construction of the adult intuitive biology.

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Finally, I dedicate this thesis to my mother, Dona Simpson Johnson, who was my best friend and my favorite teacher. I'm sure she would be as relieved as I am that this is finally done.

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Why Dogs Have Puppies And Cats Have Kittens: Young Children's Understanding of Biological Origins

Everyone agrees that one of the primary explanatory goals of research in cognitive development is to understand the learning mechanisms which enable children to learn and acquire the vast array of adult knowledge and skills. Having agreed upon this goal, it is also easily agreed that a prerequisite to its accomplishment is an exact characterization of what is learned or acquired. One major advance in this direction is seen in the recent turn toward the study of domain-specific knowledge (Chomsky, 1980; Carey and Spelke, 1992). Within the framework of domain-specific reasoning, work on the nature of conceptual domains suggests that explanatory theories are the central organizing force of these domains (Carey, 1985, 1988; Gopnik and Wellman, 1993; Wellman and Gelman, 1992). There are various ways to construe the theory view of conceptual representation and development. We take as our general stance that which is also adopted by Carey (1985, 1988) and Wellman and Gelman (1992). A theory-domain is characterized by three interdefined components. First, there is a distinct ontology. Second, there are phenomena involving the members of the ontology. Finally, there is a set of explanatory principles and causal relations which allow reasoning about the phenomena of the domain in question but not other domains.

One of the goals of research in conceptual development thus becomes the descriptive characterization of the existing domains and their contents at various points in development; e.g. infancy, early childhood, middle childhood, and beyond. Work has progressed along these lines, resulting in explications of domains of mechanics (Spelke, 1991), psychology (Leslie, 1992; Gopnik and Wellman, 1993; Perner, 1991), matter (Smith, Carey, and Wiser, 1985; Karmiloff-Smith, 1988), and biology (Carey, 1985; Keil, 1989) to name a few. Within each of these domains, different organizing theories have been detected with advancing age. The characterization of these different theories are a prerequisite to any of the important goals within the field of conceptual development, such as the identification of the innate conceptual architecture or the characterization of conceptual learning mechanisms.

This paper is intended as one step in the ongoing effort to characterize young children's knowledge in the domain of biology. Specifically we will focus only on the details of one aspect of biological knowledge, the origins of animals' species kind identity and individual properties.

The origins of properties: inheritance versus essentialism

Recently, developmental researchers have been studying young children's interpretations of many biological phenomena in search of evidence that young children have an autonomous domain of biology earlier than that suggested by Carey (1985). Among the various biological phenomena under investigation, several studies have focused on children's understanding of the origins and development of animals and their properties. These studies fall into roughly two groups, those specifically addressing children's concepts of biological inheritance (Springer, 1992; Springer and Keil, 1989; Solomon, Johnson, Zaitchik, and Carey, 1994) and those specifically addressing children's essentialist beliefs about biological kinds (Gelman and Wellman, 1991; Keil, 1989; Guntheil and Rosengren, 1993). In addition there have been subsequent interpretations of essentialist studies as evidence of inheritance concepts (Wellman and Gelman, 1992; Hirschfeld, 1993). In fact we believe that these two research thrusts are neither as independent nor as easily reconciled as may have been previously believed. In order to understand children's theories of property origins we will look closely at what we think the adult's inheritance theory of property origins is and how recent research addresses this issue in children. Then we will turn to research which addresses children's essentialist beliefs of property origins and discuss its relationship to the work on inheritance. We begin with the adult notion of inheritance.

The inheritance theory of property origins

In the naive biology of American adults inheritance is the name given to the passing of traits from parents to offspring via biological reproduction. This notion interacts with the broader phenomenon of family resemblance. The phenomenon of family resemblance refers to the accepted 'fact' that members of families tend to be more like each other than like non-family members. This applies to traits of many causally distinct types. For instance, family members may share body traits like eye color, body shape, internal abnormalities, and height at maturity; mental traits like intelligence, shared beliefs, or schizophrenia; or social traits like wealth, skills of etiquette, generosity, or status. For average adults, the concept of biological inheritance explains some, but by no means all, of these types of family resemblance. Biological inheritance might explain shared traits like internal abnormalities and eye color (body traits), schizophrenia (mental traits) and for some people maybe even generosity (a social trait). On the other hand, mechanisms of teaching or shared environment go a long way in explaining shared beliefs (a mental trait) or skills of etiquette (a social trait). In addition there are social and economic mechanisms which explain family resemblance of wealth and status. Notice though, that the class of traits for which the adult notion of biological inheritance has explanatory power does not perfectly coincide with the class of body traits. And the class of traits for which teaching has the most explanatory power is not just mental traits. Although most people believe that members of a given family are likely to be more similar in intelligence to each other than to non-family members, most people explain this fact in terms of both biological inheritance and factors of shared environment. Similarly family members can all share body shape if they have shared eating environments. If they have too little food, they might all be thin, or if they have too much food they might all be fat.

The question of exactly what class of traits are covered by the adult's theory of biological inheritance, and therefore should be sought in the child's is a difficult one. Clearly there is no way to know a priori what adults or children think is the class of traits covered by inheritance. From the examples described it appears to be less straightforward than the class of all physical traits or all body traits, although these might stand in as good approximations. The case remains that for adults and children alike, the belief in general family resemblance serves as a good heuristic when reasoning about either body, mental, or social phenomena, since the typical family tends to share all of these traits by virtue of mechanisms of inheritance, teaching, shared environment, or economics. Knowing an individual's family membership provides relatively strong predictive power for that individual's properties, of all sorts.

There is however, a class of situations where the simple heuristic of family resemblance breaks down as a result of the specific reasoning required for different classes of individual traits. These are situations where families exist whose members share the psychological and social aspects of familes, but do not share a biological relationship, such as adoptive or step familes. In these cases, adults with distinct notions of mechanisms of biological inheritance, teaching, and shared environment, will draw very different conclusions about family resemblance depending on the particular trait in question. This observation suggests a specific paradigm for examining the extent to which young children have differentiated these types of mechanisms. Children can be told stories about offspring who have both biological parents and adoptive parents and then asked to reason about which parent the offspring will resemble. The patterns of their answers, as a function of trait type (body, mental, social, etc.), can then be used to infer the extent to which they have differentiated distinct causal mechanisms of resemblance.

It is important to recognize that while young children may not have the naive biological theory of inheritance for American adults, that need not be the only possible biological theory. For certainly what makes inheritance a biological theory is not an underlying belief in modern genetics or cell theory. What makes it biological is the fact that it is reasoning which is specific to a particular given domain, independent from other domains in that individual's conceptual system. Therefore, in the adoption paradigm described above, all children have to do to demonstrate an understanding of an independent biological mechanism of inheritance is to differentiate it from other mechanisms in their bag of explanatory tricks.

And so we come to the question addressed by recent researchers concerned with whether or not children have a inheritance theory. Specifically, do young children have a theory of inheritance, either the adult's theory or their own, to cover the biological aspect of family resemblance. If the child's understanding turns out not to display domain-specificity, we will not call that understanding knowledge of inheritance. By these criteria, knowledge of the general phenomenon of family resemblance alone does not constitute knowledge of inheritance. We will briefly review the results from various labs keeping in mind the discussion above as a reminder of what we must show before we can agree that children possess an understanding of inheritance. At the very least, children must be able to disambiguate the biological and psychological/social aspects of family resemblance. * Finally, if children are to be said to have some approximation of the adult theory, they must reason about the biological aspects in terms of birth, as birth serves as part of the explanatory mechanism in the adult theory. However, children need not be like adults in order to have a biological theory. They may have some other biological theory which does not implicate the birth process. But it must implicate SOME specific process, mechanism, or principle which is not used in other domains.

Springer, in collaboration with Keil, began the inquiry by conducting several related studies of the preschooler's understanding

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* Psychological/social aspects being defined as aspects for which there is parallel, positive evidence of their embedding in a psych/social domain. Any particular property which might seem psychological to an adult could be counted as biological by a child by virtue of all the arguments made so far.

of the origin of animal properties. These studies led them to conclude that preschoolers have a theory of inheritance (Springer, 1992), and that it is specifically a sort of teleological, Lamarkian theory, rather than the adult's genetic theory (Springer and Keil, 1989). So for instance, Springer and Keil claimed preschoolers believe that if an parent has a physical trait with direct consequences for biological functioning. offspring will share that trait but that parents and offspring will not share physical traits with social consequences. Springer and Keil came to their conclusions on the basis of experiments which failed to disambuigate the biological and social aspects within a single family. Therefore, although their results demonstrate very clearly that children of these ages have strong beliefs about family resemblance in general, it is impossible to use these results to claim children have an *inheritance* theory for the origin of properties.

In response to this problem, Solomon, Johnson, Zaitchik, and Carey (1994) conducted a study which did disambiguate between the biological and social aspects of family membership within the context of people. We devised a story in which a baby was born to one parent and adopted and raised by another. Children were asked to predict whether the little boy would be more likely to resemble the birth parent or the adoptive parent when he grew up on both physical traits and beliefs. In this way the social and biological aspects of the family relationship were disambiguated. In order for children to display a biological understanding of inheritance they had to use both the information about the little boy's birth and upbringing to make the adult's predictions. The results clearly showed that only thirty to forty percent of preschoolers (ages 4 and 5) were able to utilize the distinction between the birth and adoptive parents, whereas eighty-eight percent of seven- to eight-year-olds and all adults could. The preschoolers and half of six-year-olds seemed to rely instead upon an undifferentiated notion of family resemblance. The majority of preschoolers were as likely to predict that the boy had green eyes like the adoptive parent as they were to predict that he had brown eyes like the biological father. It was not until the age of seven that the majority of children began to systematically claim that offspring *physically* resemble *birth* parents, but acquire the same *beliefs* as *adoptive* parents. These results directly contradict those of Springer and Keil and cast serious doubt on the possibility that a theory of inheritance is a major contributer to an automous biological domain in preschoolers.

The results of Solomon et al were achieved using tasks which required children to reason only about the origins of properties in a within-species context, specifically about people. Gelman and Wellman (1991), conducted a series of studies addressed at young children's essentialist beliefs about animals. One of these studies involved an adoption paradigm across species, in which very young children appear to predict the properties of animals based on the animals biological parentage. If this is true then it may be that children do in fact have an understanding of inheritance much earlier than Solomon et al credits them with. Before drawing this conclusion we will briefly consider the issues of essentialism which motivated Gelman and Wellman's study.

Essences and the essentialist theory of property origins

The notion of essences is taken originally from the philosophical literature and more recently from the psychological literature on concepts. The philosophical view makes the claim that objects, particularly natural kinds, have essences upon which an object's identity and properties depend (Locke, 1894/1959). The notion of essences which Gelman and Wellman subscribe to is slightly different and is owed in large part to the work of Medin and his collaborators (Medin, 1989; Medin and Ortony, 1989). Psychological essentialism, as it has been called, refers not to a property of objects themselves, but rather to a property of our representations of objects. That is we believe and act, perhaps wrongly, as though objects have essences. In this context, Gelman and Wellman (1991) talk about our belief that essences are "those insensible parts or cores that enable or cause the sensible qualities of an object. Essences are often unspecifiable, and by their nature require an inference about the deeper organization or disposition." p.215.

Gelman and Wellman's recent work is an attempt to show that children, like adults, reason in terms of these unspecifiable essences. This attempt is part of a long effort by Gelman to show that children can reason in terms beyond the directly observable (Gelman and Markman, 1987; Gelman, 1988). Her success has been joined by similar successes by Keil (1989). More recently, the existence of children's essentialist beliefs has been offered as a possible example of children's domain-specific reasoning in the domain of intuitive biology (Wellman and Gelman, 1992; Keil, 1992).

Gelman and Wellman's evidence comes from a series of experiments in which children are led to reason about an object's identity based on the presence or absence the object's insides or an animal or plant's properties based on the environment in which they were raised. In one adoption study they showed that children as young as 4 years old know that a baby cow raised by pigs will have the characteristic traits of a cow rather than a pig when it grows up. Furthermore they know that this is true even though as a baby, the animal had characteristic traits of neither species. The original interpretation of their results focused on preschoolers' belief in an intrinsic nature or essence of species kinds, which determines the developmental course of an animal despite conflicting environmental influences. These studies do seem to demonstrate that preschooler's believe that different species have different characteristic natures which, though not manifested at birth, develop during life and are uneffected by environmental influences.

More recently, in the context of probing children's domain-specific reasoning, these results have been used to argue that children have an understanding of biological inheritance (Wellman and Gelman, 1992; Hirschfeld, 1993). This interpretation is premature for a simple methodological reason. The protocol in these studies intentionally specified the species identity of the baby, thus insuring that the task could not be interpreted as one of species kind origin. In fact the protocol required children to explicitly recall the baby's kind identity before they were allowed to make the property judgments. It is unclear how the children would have responded had they not been explicitly told that the baby was a cow. Before we can even begin to consider whether these results show an inheritance theory of property origins, we must show that children make the same judgments even when they are not explicitly told the kind identity of the animal.

Furthermore, regardless of methodological problems, the temptation to use these results as evidence for both an essentialist theory and an inheritance theory raises an interesting theoretical point. Ultimately both inheritance and essentialism, as used by all of the researchers discussed, are candidate explanatory theories for the same phenomenon, i.e. the origins of specific properties. The inheritance theory, on the one hand, points to birth, reproduction, and the biological relationship between parents and offspring as central components of the causal story. The essentialist theory, on the other hand, points to some internal, unseen essence as the causal force which determines the unfolding of specific properties.

We designed a new set of tasks to address the simple methodological problem in Gelman and Wellman's adoption tasks. Despite our criticisms of the Gelman and Wellman protocol as a true inheritance task, we grant the possibility that their results may be due to the construction of an inheritance theory earlier than that credited by Solomon et al. Intuitively, it seems very hard to believe that there exists even a single five-year-old who does not know that dogs have dogs and not cats.

Factual or Predictive versus Explanatory Knowledge

The intuition that even preschoolers know that dogs have dogs and cats have cats, raises another interesting issue, an issue also implied by our analysis of family resemblance concepts. Is it possible for children to go through a stage in their construction of a biological theory, where they know particular facts about 'biological' entities in the world before they have constructed a biological theory in which to interpret and explain those facts. So for instance, might preschoolers know the fact that dogs give birth to dogs and cats give birth to cats before they have embedded this knowledge into an explanatory relationship such that they understand that a dog *is* a dog, *because* (or if and only if) a dog gave birth to it. In other words, what evidence do we have to believe that children have ever asked themselves the questions, "Why is a dog a dog?" or "How did this dog come to be a dog?" It remains a viable possibilty that most preschoolers are as yet unaware that there is a question to be answered* .

The same can be said for the analysis of the child's concept of family resemblance. Some researchers have taken the claim of Solomon et al to be that children have a psychological theory (i.e. belief in psychological causal mechanisms) to account for physical properties (Hirschfeld, 1993) On the contrary, the claim is not nearly so radical. Rather it can be read to claim that children have *no* causal mechanisms for these phenomena, probably because they have yet to realize that there is a question to be answered. The answer to this question would be the knowledge provided by a *theory* of biological inheritance. Instead they rely on the simple, but reliable, predictive knowledge of family resemblance which answers the question, "What do dogs give birth to?" rather than "How do dogs come to be dogs?".

The type of distinction suggested here corresponds to a distinction made in the philosophy of science literature between predictive knowledge and explanatory knowledge* . Roughly the distinction is based upon the observation that all knowledge which explains also predicts, but that not all knowledge which predicts, also explains. An example of this is readily seen when considering

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* The reader is referred to Bromberger (1992) for an interesting and thorough discussion of different types of 'not knowing'.

* For a good review of these distinctions see Salmon, W. (1989).

perfectly correlated but non-causally related events. For instance, you might give someone the task of learning to predict what color a card will be based on its shape, training them on green squares and red circles. People can readily learn to predict that the squares will be green and the circles will be red, but nowhere in that knowledge is an explanation of greenness in terms of squareness. Such an interpretation would amount to an assumption that the nature of squareness *causes* greenness.

The corresponding example in the philosophical literature is the flagpole and its shadow, credited to Bromberger (Salmon, 1989). Bromberger pointed out that the explanation for why a shadow cast by a flagpole is the length it is involves reference to the height of the flagpole along with a theory of photons. But the explanation for why the flagpole is as tall as it is has nothing to do with the length of the shadow, the direction of light, or a theory of photons, despite the fact that you can readily *predict* the height of the flagpole given these pieces of information.

Recent work by Carey, Johnson, and Levine (1993) supports this distinction with the finding that in some forms of mental retardation quite good factual and predictive knowledge about animals is common despite a complete absence of explanatory biological knowledge. Similarly, work by other researchers also suggests that it is not uncommon for normally-developing preschoolers to know the facts of birth (babies come from the mommy's tummy) before that knowledge is embedded in a theory of reproduction and origins (Bernstein and Cowan, 1975; Goldman and Goldman, 1982).

The following studies were designed to examine exactly these issues. We want to know three things. 1) Can preschoolers use the knowledge of a birth parent relationship to predict species kind (*do* they know that dogs have dogs and cats have cats? 2) If preschoolers have this knowledge, is it embedded in an explanatory understanding of the mechanism involved, i.e. reproduction and inheritance? 3) Can preschoolers use information about birth and environment to predict or explain individual *properties* of animal offsprings where they could not in people (Solomon et al)?

STUDY 1

This study examined whether children can use information about a birth relationship to 1) predict and 2) justify species kind identity. Children were told two cross-species adoption stories, one of a baby born to a horse, but adopted and raised by a cow and the other of a baby hatched from an egg laid by a duck, but raised by a chicken. After each story the children were asked, "When the baby grows up, what kind of animal will it be? " and "Why?"

Subjects

Subjects were sixteen children at each age of four, five, six, and seven years and twelve adults. Children were recruited from Cambridge area daycare centers and elementary schools. The four-year-olds were between the ages of 4;3 and 4;11 with a mean age of 4;7. The five-year-olds were between 5;0 and 5;10 with a mean of 5;3. The six-year-olds were 5;11 to 6;11 with a mean of 6;5. The seven-year-olds were between 7;1 and 8;2 with a mean of 7;5. The adults were college undergraduates. One additional four-year-old was also tested but eliminated for failure to pass the comprehension probes.

Procedures

Each child was read two stories, a duck/chicken story and a horse/cow story, (see Table 1), counterbalancing for order of story. The stories were accompanied by hand drawn sketches of each adult animal. The sketches were charicatures in the sense that they were intended to clearly depict a particular species of animal with the minimum amount of detail.

TABLE 1. Cross-Species Adoption Stories for Study 1

Duck/Chicken Story

Once upon a time there was a farm with a big barn and a pond. On the edge of the pond lived a family of ducks. One day the mama duck laid an egg in her nest. But that night she accidently knocked the egg out of the nest and lost it in the dark grass. The next day the farmer came along and found the egg. He thought it must have rolled out of the chickens's coop, so he picked it up and took it to the mama chicken's nest. The mama chicken sat on the egg along with all her other eggs. And when the egg hatched, she raised the baby with her other children so they all grew up together. They played together, ate together, and slept together. The little baby was very happy living in the chicken coop with his wonderful family. Now the baby is all grown up and I'm going to ask you some questions.

Horse/Cow Story

Once upon a time there was a farmer with a big barn filled with all different kinds of animals. In the barn he had a sweet, lady horse. One night the horse gave birth to a little baby. That same night the lady horse got very sick and died without ever seeing the baby. Fortunately there was a kind and gentle lady cow living in the barn with her family. The lady cow immediately adopted the little baby. She raised the little baby with her other children. They all grew up together. They played together, they ate together, and they slept together. The little baby was very happy living in the barn with his wonderful family. Now the baby is all grown up and I'm going to ask you some questions about what he's like as an adult.

The children were tested for comprehension of the story with the following probes, "Who gave birth to the baby?" and "Who raised the baby?" (If a child did not seem to understand the second question they were given the opportunity to answer the alternative question "Who did the baby grow up with?" This was intended to allow for children who understood the story, but did not know the word "raised". Both locutions ("raised" and "grew up with" were used in the story, so this gave the child no extra information). If the child failed either the birth or the nurture probe the story was repeated and the child was again probed for comprehension. If the child still failed to answer the probes correctly that child was excluded from the main analysis. These probes served two purposes; to insure that the children were paying attention to the story and to insure that the children knew the concepts of 'birth' and 'raising' at some level. After the child had successfully answered the probe questions, they were then asked "When the baby is all grown up what kind of animal is it?" and "Why?" All responses were recorded by the experimenter.

Results

Kind Judgments

Each item was coded as either a birth parent judgment or an adoptive parent judgment. Data were collapsed over subjects within age groups and are shown in Figure 1 as the percentage of items on which subjects judged the baby would grow up to be a horse or a duck.

FIGURE 1. Study 1 total percentage of birth parent kind judgements.

4 yrs	5 yrs	6 yrs	7 yrs	Adults
62	75	88	97	100

A 2 x 2 x 5 ANOVA (story, horse vs. duck; order, horse story first vs. duck story first; and five levels of age) showed there was a significant main effect of age, $F(4,66)=3.40$, $p<.05$ and no main effects of story or order of story. Preplanned t-tests were used to compare performance at each age against a chance level of 50%. The four-year-olds were not significantly above chance, $t(15)=1.44$, $p=.16$. Five-, six-, and seven-year-olds were all above chance; five-year-olds, $t(15)=3.22$, $p<.01$; six-year-olds, $t(15)=6.31$, $p<.001$; and seven-year-olds, $t(15)=15.0$, $p<.001$. These data seem to show that as a group children are able to predict species kind membership on the basis of birth parent information with better-than-chance accuracy by the age of five years. This is two years *earlier* than Solomon, et al. claim children understand the significance of the birth relationship with respect to a person's individual properties, and a year *later* than Gelman and Wellman's claim that children understand the inheritance of species kind. Independent of whatever age we finally agree the majority of children show an understanding of these issues, these data show a definite developmental trend in which the youngest children are clearly not at ceiling. This suggests that knowledge of these relationships is probably not present from the very beginning and must be learned. Subjects' justifications were analyzed in order to clarify whether or not subjects' responses were driven by theoretical explanatory principles and if so what sort.

Kind Justifications

Justifications were coded into categories suggested by the Gelman and Wellman's essentialist studies and the Solomon et al inheritance studies. One experimenter coded all of the justifications and a second experimenter coded a subset of approximately eighty percent of the responses. This led to an initial agreement between the two experimenters of eighty-nine percent. The categories into which responses were placed were *Origins, Intrinsic Nature, Mother's Kind, Nuture,* and *Other/Don't Know*. The following are brief descriptions of the criteria used for assigning a justification to each category.

Origins- These included any justification that referred to where or who or what the baby came from. Mention of birth per se was not necessary, but it was sufficient for inclusion in this category. Examples include, "because it was born from the horse," "because it came from the horse, " "because the horse made it," or "because the duck laid it".

Intrinsic Nature - These included any justification that invoked what kind of animal the baby was at an earlier point in its history in order to explain what kind it would grow up to be. These specifically did not invoke the animal's origin as an explanatory point. As such they answer a very different question than the experimenters believed they were asking. Examples of these are, "because it was a horse when it was a baby" and "because all ducks grow up to be ducks". There are at least two empirical reasons to believe the distinction between origins and intrinsic nature explanations. First, intrinsic nature explanations were used by children to justify both biological and adoptive parent judgements (18 percent of birth parent judgments were intrinsic nature explanations and 22 percent of adoptive parent judgments were). Conversely, origins explanations were used almo*r* exclusively to justify biological parent judgements, suggesting that they really are playing different roles in children's theories. Second, intrinsic nature explanations almost disappear by the age of seven years. Seven-year-olds apparently realize that this is not an appropriate explanation *for the question at hand.*

Mother's Kind - These included any response that justified the baby's kind by pointing out the mother's kind without any mention of the mother having some relationship to the origin of the baby. This is a type of family resemblance explanation. These tended to be very straightforward and of the form, "because its mother was a horse." Mother's Kind justifications were also used to justify both birth parent and adoptive parent judgments.

Nuture - This category included any reference to the environment in which the baby lived or grew up or any teaching explanations. Examples included things like, "because he grew up with the horse."

Other/Don't Know - This final category actually includes two types of responses, the truly uncodable and "don't know". A response was deemed uncodable if it did not fit into any of the four categories given above. The majority of responses in this category were "don't knows", but there were also some responses of the type "because it's a duck/horse" (which is no explanation at all) as well as "because I knew he was" or "because it was a mishappening".

Figure 2 shows the percentage of responses which fell into each category by judgment type and age*. Several interesting results are suggested by this figure. Importantly, for the most part all of the subjects were able to give explanations. However, we can see from this figure that far fewer children justify their judgments in terms of the origins of the animal than one would suspect based on the judgment data in Figure 1 alone. This suggests that perhaps some of their apparent success is based either on chance (children have a fifty percent chance of being correct on each item by chance alone) or simple, non-explanatory, predictive knowledge.

Also notice that among the four-year-olds, the usage of the origins explanation is higher than either the five- or six-year-olds. This is an apparently anomolous result until we notice that a four-year-old also justified an adoptive parent judgment with an origins explanation. This leads us to suspect that for some of the younger

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* Due to experimenter error a few children were not probed for justifications. For this analysis those children were excluded and the data is presented as percentages rather than numbers of children.

FIGURE 2. Study 1 percentages of all kind justification responses in each explanatory category by age group and judgment responses.

Age	4 yrs		5 yrs		6 yrs		7yrs		Adults	
Judgment Type	B	A	B	A	B	A	B	A	B	A
Origins	67	12	41	0	48	0	70	0	71	-
Intrinsic Nature	17	0	23	17	32	100	9	0	8	-
Mother's Kind	11	38	9	0	4	0	0	0	17	-
Nuture	0	12	0	0	4	0	0	100	0	-
Other/Don't Know	6	38	27	83	12	0	22	0	4	-

children, the explanation data actually overestimates their true understanding. Recall that our protocol emphasized the birth information to an extreme, requiring the child to focus on that information and reproduce it before proceeding with the judgment. In this respect the birth relationship was highlighted independent of it's explanatory role. Given this fact it is all the more surprising that the five- and six-year-olds still failed to invoke it in their explanations.

By the same token, it is important to point out that no age group consistently used nuture explanations to justify their kind judgments. Only one four-year-old, one six-year-old, and one seven-year-old did so. Based on the argument above concerning the protocol's heavy emphasis of specific facts, i.e. the birth and nuture information, these few nuture explanations could be a simple parroting of the nuture relationship emphasized in the story and reemphasized in the comprehension probes. Certainly, we do not want to claim that children have a nuture theory of species kind origin.

The reliance of five- and six-year-olds on intrinsic nature explanations is substantial. This suggests the possibility that a large number of them have failed to grasp that there is even a question with respect to the animal's origin which requires an explanation, choosing instead to answer a question more concerned with the animal's development. Notice that these responses have virtually disappeared by the age of seven.

Finally, a substantial proportion of the four-year-olds adoptive judgments are justified by Mother's Kind explanations, which presumably reflect a reliance on pure family resemblance concepts. On the other hand, some of the adults also use these explanations, raising the possibility that this form of explanation reflects a pragmatic constraint against repeating cneself. Presumably if this justification type is the result of a pragmatic constraint at work, then these explanations only appear in the company of other more explicit explanations. This should be apparent one way or the other in an analysis of individual subject performance.

In general these justification data seem to contradict the judgment analysis. On the whole fewer children at all ages seem to gave origins explanations than made the birth parent prediction. And a substantial percentage of the children failed to interpret the question as one of the *animal's* origin at all, as reflected in the numbers of intrinsic nature explanations. However, there is the possibility that these codings underestimate subject's understanding for simple pragmatic reasons, as suggested by the adult data. Therefore, the next analysis was performed in order to detect distinct patterns of individual responses within age groups. This analysis took into consideration the combination of each subject's judgements and justifications and includes statistical analyses of the findings.

Judgment by Explanation Patterns

We divided subjects into four patterns based on their judgments and explanations combined. We postulate that a subject can be credited with an inheritance theory of species kind only if they give birth parent *judgments* for both stories and *justify* their judgment with an origins explanation at least once. For the pragmatic reasons discussed, we did not require a subject to justify both judgments with an origins explanation. For instance a subject could say, "because it was born by the horse," (an origins explanation) on the first story and then simply say, "because it's mother was a duck" (a mother's kind explanation) on the second story, and still be credited with the inheritance theory if they gave the birth parent judgment for both stories. These children were placed into the Origins pattern group. The three other types of patterns we assigned subjects to were a Non-origins birth pattern, where the subject predicted the birth parent's kind on both items but failed to ever give an origins explanation, an Adoptive pattern where the subject gave adoptive parent judgments on both items and justified them with any explanation type, and finally a Mixed pattern, where the subject gave one of each type of judgment accompanied by any explanation type. The results as a function of subjects in each pattern group for each age are shown in Figure 3.

A 2-way chi-square over the 5 levels of age and 4 pattern groups as reflected in Figure 3 was performed, reaching marginal significance, $X^2(12) = 20.38$, $p < .10$. Because we are most interested in the distinction between children falling into the Origins pattern versus any of the non-Origins patterns, a secondary chi-square analysis was performed on the data after collapsing the four pattern groups into two groups; Origins and non-Origins. This resulted in a $X^2_{(3)} = 13.59$, $p < .01$.

FIGURE 3. Study 1 percentages of subjects in each pattern group by age (number in parenthesis is the actual number of subjects in each group.)

	4 yrs	5 yrs	6 yrs	7 yrs	Adults
Origins	33 (5)	33 (5)	40 (6)	67 (8)	92 (11)
Birth/ Non-origins	20 (3)	33 (5)	40 (6)	25 (3)	8 (1)
Adoptive	34 (5)	20 (3)	7 (1)	0 (0)	0 (0)
Mixed	13 (2)	13 (2)	13 (2)	8 (1)	0 (0)

We can see several things when we consider subjects' judgments in combination with their explanations. Adult performance goes nearly to ceiling with eleven of the twelve subjects giving the origins explanation at least once. From this fact we conclude that adults are sensitive to the pragmatics of the situation when giving explanations, leading them to give some general, non-specific mother's kind explanations in combination with the more specific origins explanations. However notice that when calculated as a function of individual children, the percentage of origins reponses decreases. This confirms our suspicion that the group data only overestimates performance for children. Nonetheless, two-thirds of the seven-year-olds and thirty to forty percent of the younger children interpret and respond to the question in a way compatable with the intuitive adult theory, in terms of origins and thus inheritance. Interestingly, the apparent success of four-year-olds' use of origins explanations goes away when viewed in the context of their judgments. Both of the four-year-olds in the mixed condition gave origins explanations as well as adoptive parent judgments, suggesting that they were simply parroting the information from the story, without understanding it. These results are completely consistent with those from Solomon et al's study on the origin of properties. A minority of preschoolers have embedded their knowledge of birth into a causal theory of inheritance and there is a developmental trend such that the majority of seven-year-olds have.

Study 1 leads us to conclude that children are not as sophisticated about the inheritance of species kind membership as recent claims have suggested. In terms of being able to reason about judgments of species kind with an origins theory of birth, they seem to perform approximately the same as children do on questions of people's inheritance of individual properties. If anything, these results are slightly behind the Solomon et al results where nearly all seven-year-olds showed evidence of an inheritance theory.

However, with respect to the simple ability to predict species kind, children seem to be succeeding slightly earlier. This can be seen by comparing the proportions of the children in the non-origins birth pattern to the proportion in the adoptive pattern. A disproportional number of birth pattern children would suggest an implicit sensitivity to the birth information. This disproportional pattern is seen for the six-year-olds, among whom birth bias children outnumbered the adoptive bias children six to one, a result that you would not predict by chance.

This appears to be evidence for the predicted lag between learning the factual knowledge about birth and embedding that knowledge into an explanatory theory. On the basis of this data most of the six-year-olds have learned something about birth. Forty percent of them have embedded that knowledge into a theory of animal origins. Another forty percent or so, minus some portion to account for chance, are in fact sensitive to the predictive aspect of birth. They may know the *facts* about the relationship between birth and family relationships, but they have not yet interpreted it for themselves as an *explanatory causal mechanism*. Under this interpretation the children know that dogs give birth to dogs, but they have not yet embedded this in (or constructed) an explanatory framework of inheritance which leads to the explanation that dogs are dogs *because* a dog gave birth to them.

For those readers reluctant to rely too heavily upon the subtleties of children's free explanations, we recognize that an alternative interpretation exists for explaining the disproportional numbers of birth and adoptive patterns among six-year-olds. It could simply be that our coding scheme is too strict. By accepting only origins explanations and excluding intrinsic nature and mother's kind explanations, we may have simply underestimated the number of children with explanatory theories, and overelaboratated the distinction between predictive and explanatory knowledge. This alternative explanation seems unlikely given three observations. First, both intrinsic nature and mother's kind explanations were used to justify adoptive parent judgments as well as birth parent judgments. Second, both types virtually disappeared by the age of seven. Third, when mother's kind explanations reappeared for adults, it appears they were used for pragmatic reasons, since they were used only in the company of a more explicit explanation. Nonetheless, with this objection in mind, Study 2 probes children's reasoning about birth and inheritance with a task which allows us to draw conclusions on the basis of the children's judgments alone.

STUDY 2

Study 2 was designed to probe children's understanding of inheritance with a methodology that we know is sensitive to children's causal understandings of property origins without relying on explanation data. A cross-species property inheritance task was designed. A property inheritance task is one where the subject is required to judge which parent the offspring will share particular traits with. Different trait types such as physical properties or beliefs are contrasted. If children understand inheritance, it should be evident in their judgement patterns. They should project the parent's traits to the offspring differentially depending on what type of trait it is. Children in Solomon et al showed good success with differentiating property types by the age of seven. In addition, half of six-year-olds and a third of five-year-olds could be credited with an inheritance theory on the bases of this type of judgment pattern. If our Study 1 interpretations underestimate children's knowledge about inheritance, and if Gelman and Wellman's cross-species adoption tasks reflected inheritance theories rather than essentialist beliefs, then a property task across species should yield higher success rates than either Study 1 here or Solomon et al.

Subjects

Subjects were 16 children at each age of four, five, six, and seven years and 16 adults. An additional ten four-year-olds and one five-year-old were also tested but not included in the analyses due to failure to correctly answer the comprehension probes. The successful four-year-olds were between the ages of 3;8 and 4;11 with a mean age of 4;5. The five-year-olds were between 5;2 and 5;10 with a mean of 5;5. The six-year-olds were 6;1 to 6;11 with a mean of 6;5. The seven-year-olds were between 7;1 and 8;6 with a mean of 7;7. The adults were non-biology major undergraduates. The children came from area schools, a day camp, or were siblings of subjects visiting another study group in the lab.

Procedure

Subjects were read one of the two stories from Study 1, accompanied by the same pictures and immediately followed by the comprehension probes. Subjects were again given two chances to successfully complete the comprehension probes, otherwise they were excluded from the analysis. After the comprehension probes, the subject was told they were going to be asked about what they thought the baby would be like when it was all grown up. Subjects were presented with twelve items, four each from the three categories (physical, beliefs, and behaviors; see Table 2). Unlike Gelman and Wellman's procedure, traits were all chosen to minimize their perceived association with one or the other species. The hope was that this would minimize the tendency to judge on the basis of species kind alone without reasoning about individual properties. Traits were blocked by category and the order of blocks was counterbalanced. Each item consisted of a pair of traits, one belonging to each adult. The child was asked which trait the baby would have, e.g., "The cow has a brown nose and the horse has a black nose. When the baby is all grown up will it have a brown nose like the cow or a black nose like the horse?" The order of presentation of parents within each item was held constant for each subject and

TABLE 2. Property items for Study 2

Horse	Cow	Duck	Chicken
	Physical Properties		
•Black nose	•Brown nose	•Black eyes	•Brown eyes
•Thick fur	•Thin fur	•Thin blood	•Thick blood
•16 ribs	•14 ribs	•Long feathers	•Short feathers
•Smooth tongue	•Rough tongue	•Rough skin	•Smooth skin
	Beliefs		
•Did NOT know where special food was kept	•DID know where special food was kept	•Did NOT know where to hide in bad weather	•DID know where to hide in bad weather
•Believed the farmer bought their hay	•Believed the farmer grew their hay	•Believed there were foxes in the woods	•Believed there were foxes in the fields
•Believed pigs eat straw	•Believed pigs eat corn	•Believed fish eat seaweed	•Believed fish eat bugs
•Believed there were NO wolves in the woods	•Believed there WERE wolves in the woods	•Did know how to get into the corn shed	•Did NOT know how to get into the corn shed
	Behaviors		
•Ate in the afternoon	•Ate in the morning	•Was afraid of strange animals	•Was afraid of strange noises
•Slept outdoors	•Slept indoors	•Sat in the shade	•Sat in the sun
•Rubbed against trees	•Rolled in the grass	•Scratched her legs alot	•Stretched her wings alot
•Chased	•Chased	•Liked to be	•Liked to be

crickets	butterflies	alone	in crowds

counterbalanced across subjects. The pictures were pointed to with each trait in order to help the subject follow the questions. After the first question in each block, the subject was asked to justify their response. At the end of the twelve items the subject was asked one final question, "When the baby is all grown up, what kind of animal is it?" All of the subjects' responses were recorded by the experimenter.

Results

Property Task

Group Analysis of Judgements

As in Study 1, responses to each item were coded as either a birth parent judgment or an adoptive parent judgment. Data was collapsed over subjects within age groups. Data are shown in Figure 4 as the percentage of judgments for each property and age which were judged to be like the birth parent's property.

FIGURE 4. Study 2 percentage of birth parent properties which were attributed to the baby by age group.

	4 yrs	5 yrs	6 yrs	7 yrs	Adults
Physical	78	75	81	90	98
Beliefs	66	66	53	44	8
Behaviors	67	72	64	53	19

The main question of interest in this data is whether or not subjects respond in a way which differentiates between the three categories of properties and at what age. The results shown in Figure 5 appear to vary with both property type and age. As expected the adults made the most categorical distinction between property types, attributing virtually all of the birth parent's physical properties and none of the beliefs to the offspring. For the adults, behaviors patterned closely with beliefs, with only nineteen percent of the birth parent's behaviors attributed to the offspring. None of the children's groups responded with this clear distinction between the physical properties and everything else.

The seven-year-olds attributed most of the physical properties but also half of the beliefs and half of the behaviors to the birth parent. The six-year-olds showed a slightly smaller difference between the projection of birth parent's property types with fewer of the physical properties and slightly more of the beliefs and behaviors than the seven-year-olds. For four- and five-year-olds on the other hand, the distinction between physical properties and beliefs or behaviors all but disappears. Their performances were also practically identical to each other. They projected all three types of the birth parent's properties two-thirds to three-quarters of the time. Again, as a group only the adults systematically denied that the baby would have the beliefs of the birth parent.

A 5 x 2 x 2 x 2 x 3 ANOVA was performed on the design factors of age, story, order of parent within item, order of trait blocking, and trait type. We were particularly interested in effects of trait type and any interaction between age and trait type, since these are indications of increasing differentiation.

Several main effects and interactions were found. A main effect of trait type was found, $F(2,80)=69.91$, $p<.001$. Overall, subjects were more likely to attribute the birth parent's trait to the offspring if it was a physical trait. A main effect of age was also found, $F(4,40)=4.04$, $p<.01$, reflecting the fact that adults were less likely to attribute a birth parent's trait than the other ages. This is explained by the fact that the adults restricted their birth parent judgements to the category of physical traits, resulting in much lower overall rates of projection relative to the other age groups.

Importantly, as suggested above, there was a large age by trait type interaction, $F(8,80)=12.28$, $p<.001$, confirming that the increasing differentiation of property types with age was a real effect. No other main effects were expected or predicted. However, two other main effects were observed.

The 'order of presentation of parent within items' factor reached a significance level of $F(1,40)=10.72$, $p<.01$. Subjects were more likely to judge an item to match the birth parent if the birth parent was presented last. We are willing to believe that this is a form of a recency effect. However, we remind the reader that there was no effect of parental order in Solomon et al's inheritance task. Therefore, since the form of the studies are identical we do not believe that this is an indication of too large a memory load or too great a task demand, either of which would undermine the interpretability of the results. Rather we think it is a recency effect which is the result of the general difficulty of the task's content.

There was also a main effect of story, $F(1,40)=5.47$, $p<.05$. Unlike in Study 1, subjects' judgements were influenced by whether or not the story involved a duck and a chicken or a horse and a cow. Subjects who received the duck/chicken story were more likely to attribute traits to the birth parent overall than were those who heard the horse/cow story. In retrospect it seems possible that this is a reflection of the degree of similarity of the animals in question to people. After all, in order to resist attributing beliefs to the birth parent and thereby differentiate the parents and traits, it is necessary to entertain some notion of a mechanism by which the adoptive parent could effect the offspring. In the case of people this is clearly a domain for teaching mechanisms to be employed. It is possible that children, assume that birds are less 'teachable' than mammals and complementarily, more bound by their intrinsic natures in general.

Two interactions other than the trait by age interaction already mentioned also reached significance; a two-way interaction between parental order and order of trait blocks, $F(1,40)=4.43$, $p<.05$ and a three-way interaction between story type, parental order, and trait type, $F(2,80)=5.076$, $p<.01$. These last two interactions are likely attributable to the interplay of effects already discussed.

Post-hoc Scheffe tests were conducted on each age group to determine the extent to which each had differentiated trait types. The results were non-significant for all groups except seven-year-olds, Scheffe $F(4,16)=11.46$, $p<.05$, and adults, Scheffe $F(4,16)=177$, $p<.01$. Only the seven-year-olds and adults distinguished between the types of traits reliably enough for us to infer that, as a group, they were using knowledge of different underlying causal principles to guide their reasoning.

Analysis of Individual Patterns

The above analysis was group data, collapsed over the judgments of many subjects. The following analysis looks at individual subjects to determine how much of the success or failure of a group is shared by all of its members.

Subjects were divided up into four categories of response patterns based on how well they differentiated between the physical and belief traits as reflected by birth parent judgments. The four patterns were Differentiated, Birth Bias, Adoptive Bias, and Miscellaneous. The groups were defined by a two-step process. First, with respect to the differentiation between physical and belief traits which resulted in two groups, and then the overall tendency of the non-differentiating subjects to go with one or the other of the parents.

Differentiated patterns were ones where the subject chose at least three of the four physical traits of the birth parent and at least three of four beliefs of the adoptive parent. Behaviors could go either way even though we know that for adults at least they pattern with the beliefs. Non-differentiated patterns were then split up into three groups. Birth bias patterns were ones where at least ten of the twelve traits went with the birth parent. Adoptive bias patterns were ones where only two or fewer traits went with the birth parent (leaving ten or more with the adoptive parent). Miscellaneous was anything else. Subjects per pattern by age are shown below in Figure 5.

The number of children responding in the Differentiated pattern increases with age, but is still unexpectedly small for all but the adult group. A chi-square analysis of the five levels of age crossed with the four levels of patterns was significant, $X^2_{(12)}=43.70$, $p<.001$, confirming that there was a large effect of age on which group a subject was likely to be classified into. These results suggest that the success of the seven-year-olds in differentiating the traits as a group , was in fact due to the success of a minority of children within the group. If the Differentiated group is the group credited with an inheritance theory, the performances reflected here are far below the levels of achievement reached on the kind task of Study 1. The failures here confirm that the failure of the children in Study 1 was *not* due to a general difficulty in producing explanations and Study 1 probably did not underestimate their understanding of inheritance. Interestingly, the results of the kind inheritance task in Study 1 were more consistent with the results of Solomon et al's property inheritance task than are the results of Study 2's comparable property inheritance task. This alone is an unpredicted and puzzling result.

FIGURE 5. Study 2 percentage of subjects falling into each pattern group by age (the number in parentheses is the number of subjects in each group.)

	4 yrs	5 yrs	6 yrs	7 yrs	Adults
Differentiated	0 (0)	6 (1)	31 (5)	38 (6)	94 (15)
Birth bias	50 (8)	62 (10)	44 (7)	32 (5)	0 (0)
Adoptive bias	6 (1)	12 (2)	12 (2)	6 (1)	0 (0)
Miscellaneous	44 (7)	19 (3)	12 (2)	25 (4)	6 (1)*

On the one hand the fact that there are fewer children showing the inheritance theory of property origins in Study 2 than showed

* This adult was only one belief judgment away from being classified as a differentiated adult. In all other respects he looked just like the other adults, as can be inferred from the group data.

the inheritance theory of kind origin in Study 1, suggests there are children who understand the causal role of birth (the inheritance theory) with respect to species kind *before* they understand it for property origins. On the other hand, the consistency of the Study 1 results with the Solomon et al property task suggests that children as a whole come to understand the inheritance of kind at the *same* time as they understand the inheritance of properties.

There is one other interesting difference in the results of Study 1 and 2 which may help us to understand this apparent contradiction. A greater proportion of children at all ages produced the Birth bias pattern in Study 2 than produced the most comparable pattern in Study 1, the Non-origins birth parent kind judgments. A full fifty percent of four-year-olds, sixty-two percent of five-year-olds, forty-five percent of six-year-olds, and thirty-two percent of seven-year-olds showed the Birth bias pattern of judgments. The comparable numbers of non-origins birth parent kind judgments in Study 1 were twenty, thirty-three, forty, and twenty-five percent. The birth bias pattern in the property task may reflect a strong essentialist belief in property origins covering not only physical properties but behaviors and beliefs as well.

Solomon et al probed for children's inheritance theories of property origins in a within-species context. This circumvented any possible interference from a competing essentialist theory of property origins. When we placed the adoption paradigm into a cross-species context we in effect put children in the position of choosing between these two competing theories. As it turned out, the essentialist theory won out for the large majority of children. A possible explanation for why there appears to be less interference from the essentialist theory for the inheritance theory of species kind (Study 1) than for species properties (Study 2) lies in one simple observation. The essentialist theory does not cover the origins of the essence (the kind) itself. Rather it assumes the existence of an essence and then uses it to explain the origin of properties.

One final point is important to note. While children may be reasoning about unobservable causal forces when relying on essentialist beliefs of property origins (as Gelman and Wellman suggest), the fact that they do not differentiate the property types suggests that it is not a domain-specific reasoning principle.

Justifications

Justifications of individual property judgments were coded. One researcher coded all of the responses and a second experimenter coded a subgroup. Initial agreement on coding was 92%. The same categories used in Study 1 were used here. The one difference was in the acceptable forms of the intrinsic nature answers. Responses of the form, "because it's a duck," were not accepted as explanations of any sort in Study 1 and were thus coded as Other/Don't Know. In the Study 2 property judgments however, this form was accepted as an intrinsic nature explanation. A moment of reflection on the distinction between the two situations should make the reasoning clear. In Study 1, the question was one of kind membership, e.g. "Why is it a duck?' In this case to respond, "because it's a duck," is not an explanation of any sort. It is simply a restatement of the thing to be explained. In the property task of Study 2 however, "because it's a duck," is a genuine explanation relative to the question, "Why does it have brown eyes?" In other words, referring to kind membership is a legitimate explanation for a query about a property, in a way that it is not for a query about kind membership. In fact, it is an intrinsic nature explanation of the sort; Question: "Why does it moo?" Answer: "because it is a cow."

Figure 5 shows the distribution of explanation types by property type for adults*. It is clear from the figure that adults selectively reason about physical traits, but never beliefs and rarely behaviors, in terms of origins or birth. They occasionally use intrinsic nature explanations also for physical properties, but these they do not constrain to only physical properties in the way they do origins explanations, suggesting that for adults at least it is not a purely biological mechanism. Conversely, they reason about beliefs and behaviors, but rarely physical traits, overwhelmingly in terms of nuture mechanisms.

FIGURE 5. Adult justification data. Numbers shown are the percentage of times each type of explanation was used within each trait type.

ADULTS n=16	Physical	Beliefs	Behaviors
Origins	81	0	6
Intrinsic Nature	12	9	12
Mother's Kind	6	0	0
Nurture	3	91	78
Don't Know	0	0	3

These results show that adults clearly have two distinct mechanisms which they use differentially to reason about the origins of physical versus psychological traits. In addition it confirms that

* Because the responses from the adult classified in the miscellaneous pattern were indistinguishable from the other fifteen differentiated adults, they are included in the totals.

the specific causal theory around which they reason about physical properties is the theory of property origins centered around reproduction and birth, i.e. the inheritance theory.

Children's explanations by pattern group and trait type are shown in Figure 6. For the purpose of maintaining our focus on the differences between pattern groups, data are presented and discussed as a function of the groups. To get some sense of the strength of explanation patterns, five individual 4 x 3 ANOVAS on the frequency of each explanation type (one each for Origins, Intrinsic Nature, Mother's Kind, Nurture, and Other) as a function of the four pattern groups and the three trait types were run. These results will be described in the context of describing the group data. We are looking for converging evidence of two points; our grouping of judgment patterns and our analysis of the different explanation types. In general we are interested in whether any explanation type was used systematically by any group and whether different groups use different explanations. We are especially interested in whether or not the Differentiated group of children show positive evidence of two distinct explanations selectively employed for different property types. The employment of origin explanations specifically for physical traits and nurture explanations for beliefs would serve as converging evidence of the differentiation of the two property types demonstrated in the judgment data and allow us to conclude that this differentiation is the product of two independent theoretical domains operating on reasoning for children.

FIGURE 6. Children's justification data by pattern group. Tables show the percentage of times each type of explanation was used within each trait type by a particular judgment pattern group.

DIFFERENTIATED n=12	Physical	Beliefs	Behaviors
Origins	50	0	4
Intrinsic Nature	42	0	0
Mother's Kind	0	0	0
Nuture	0	80	58
Other	8	21	38

BIRTH BIAS n=30	Physical	Beliefs	Behaviors
Origins	30	28	17
Intrinsic Nature	33	20	22
Mother's Kind	10	7	17
Nuture	0	10	3
Other	27	35	45

ADOPTIVE BIAS n=6	Physical	Beliefs	Behaviors
Origins	0	0	0
Intrinsic Nature	0	0	0
Mother's Kind	17	0	0
Nuture	33	33	33
Other	50	67	67

MISCELLANEOUS n=16	Physical	Beliefs	Behaviors
Origins	25	6	0
Intrinsic Nature	19	0	0
Mother's Kind	6	6	3
Nuture	6	12	28
Other	44	75	69

We will discuss the use of explanations from the non-differentiated groups first and then discuss the differentiated pattern group* . Among the Birth bias children, notice that both origins explanations and intrinsic nature explanations are used across trait types. The use of origins explanations across all property types is unique to birth bias children as reflected by the interaction between group and trait for origins, $F(6,120)=2.50$, $p<.05$. The use of intrinsic nature explanations equally across trait types is not unique to birth bias children (adults also did this), but their greater overall dependence on them is, as supported by a main effect of group on the frequency of intrinsic nature explanations, $F(3,60)=3.14$, $p<.05$. Birth bias children use the origins and intrinsic nature explanations equally, along with a thin scatter of mother's kind and nurture explanations.

Notice that the overgeneralization of the origins explanation means there were children who literally answered the question "Why does the baby believe X?" with the explanation, "because it was born from the horse"(i.e. they used birth to justify what beliefs the animal held.) Like the children in Study 1 who both used the origins explanation for kind judgments and made adoptive parent judgments this usage may not reflect actual understanding of any causal role for birth, but a straight repetition of the information in the story. The use of the intrinsic nature explanations on the other hand, presumably reflect the view that species kind essence determines animals' beliefs and behavioral traits as well as physical traits. Again,

* Mother's Kind explanations yielded no main effects of either group or traits, nor did it show any group by trait interaction, suggesting that it played no major explanatory role for any group.

because this usage is across property types it can not be considered a domain-specific principle.

Among the Adoptive bias children, the most common response was either uncodable or 'don't know'. Otherwise, with almost no exceptions the only explanations that these children used were nurture explanations, which they employed across categories, beliefs and physical properties alike. This blanket use of the nuture explanation was unique to the Adoptive bias children as reflected in the group by trait interaction, $F(6,120)=7.77$, $p<.001$.

The Miscellaneous children appear swamped by 'don't know' and uncodable responses. This reinforces the impression left by their judgement patterns that they had no systematic principles with which to guide their inferences. Nonetheless, despite their overall explanatory confusion there is a slight indication of selective use of the origins and nuture explanations appropriately constrained to the physical and belief categories respectively, perhaps contributing to the interactions between group and trait for those explanations already reported. The only other group who managed to selectively used the origins and nuture explanations was the Differentiated group, suggesting that their may be a few children in the Miscellaneous group who just miss differentiating the traits on the basis of judgments alone, failing to cleanly project along the lines of properties types.

Finally, the Differentiated group is the only group for which Other/Don't Know is not the most common response. This is supported by the anova on other/don't know explanations which resulted in a main effect of group, $F(3,60)=4.10$, $p<.01$. Importantly, notice that the Differentiated group has clearly distinquished at least two distinct mechanisms which they use in complementary distribution. They use origins explanations for physical traits but never for beliefs and they use nuture explanations for beliefs and behaviors but never for physical traits. With the exception of a slight tendency in this direction for the Miscellaneous children, the Differentiated group is the only group to make this distinction. This is supported by group by trait interactions for both origins explanations, $F(6,120)=2.50$, $p<.05$ and nuture explanations, $F(6,120)=7.77$, $p<.001$. Interestingly the Differentiated children also have a tendency to use intrinsic nature explanations for physical traits nearly as often as they use origins explanations. They use this explanation far more than the adults do, but unlike the adults they restrict it to the physical trait.

The Differentiated children's restricted use of the intrinsic nature explanation as well as the origins explanations is unpredicted and suggests two possibilities. Recall that producing the differentiated pattern is our diagnostic for an understanding of two distinct causal processes, one for physical properties and one for psychological or social properties. We have assumed all along that the understood causal process for physical traits in this case is likely to implicate a birth mechanism even if children did not explicitly say so. Therefore, it is curious that children who give us the differentiated pattern, also give us the intrinsic nature explanations for physical traits. It would be informative to know whether these same children also give origins explanations. If they do it would suggest either that they have not completely let go of the essentialist theory in favor of the inheritance theory, or that the use of the intrinsic nature explanations as diagnostic of a different theory (the essentialist theory) is not completely legitimate.

However, if the origins explanations and the intrinsic nature explanations are produced by different children we have another possibility to consider. There may be two ways to achieve the differentiated pattern. Certainly it requires two distinct causal mechanisms, one for beliefs and one for physical traits. All of these children seem to understand the learning/nuture process for the case of beliefs. What is unclear is the causal process they are using to reason about physical properties. If we truly believe that children may be able to learn *factual or predictive* knowledge about birth before they have constructed an *explanatory* theory of birth, then it may be possible to achieve the differentiated pattern with a less-than-explanatory theory of the causal role of birth for either properties or kind. All children would need is the predictive knowledge of which parent is the 'real' parent (i.e. dogs give birth to dogs, not cats) in order to know which kind 'essence' the offspring will have. Children could then use the essentialist theory of property origins in combination with a nurture or learning theory of beliefs to produce a differentiated pattern. In this scenario children giving the intrinsic nature explanations would have two distinct domain-specific causal processes, but their biological theory would be a refined and constrained version of the earlier essentialist beliefs. We would conclude that it is a biological understanding for these children specifically because it *is* constrained to only physical traits, where before it was not. On the other hand, children producing the origins explanations alone can be credited with a full inheritance theory of property origins.

The data here are far too sparse to distinguish between these possiblities. However, a general look at all the children who gave either origins or intrinsic nature explanations for property origins is suggestive. Of the thirty-nine children who produced these explanation types, only six children ever produced both. This supports the claim that in fact these two explanations reflect different theories of property origins. Furthermore, the fact that both explanation types were used by both Differentiated and Birth bias children suggests that either can be construed in domain-specific or non-domain-specific ways.

In general the justification data is extremely consistent with the analysis of judgement pattern groups. The Differentiated subjects seem to have a *biological* theory which constrains their inferences of physical property origins and a psychological or social theory which constrains their inferences of beliefs and behaviors. The possibility that some have a biological inheritance theory and some have a biological essentialist theory is suggested but remains an open question. The Birth bias and Adoptive bias children on the other hand, who together constitute the vast majority of children this age, show no evidence on this task of having differentiated physical properties from either beliefs or behaviors with respect to their origins. Despite the fact that they also use origins, intrinsic nature, and nurture explanations in their justifications, the fact that they do not do so selectively with respect to property type disallows an interpretation of any of these explanations playing a domain-specific function for those children.

Kind Judgments and Explanations

Finally, one last set of data was analyzed in Study 2. After each subject completed the property judgment items, they were asked to predict what kind of animal the baby would be when it grew up and then to explain their answer. This is a replication of the question on which Study 1 was based. The only difference this time is that the question was preceded by the property task and each subject only heard one story instead of two. Results are shown first in Figure 7 for the judgments alone.

FIGURE 7. Study 2 total percentage of birth parent kind judgments.

4 yrs	5 yrs	6 yrs	7 yrs	Adults
75	88	94	100	100

A comparison between Figure 7 and Figure 1 seems to show higher percentages of birth parent judgments at all ages than in Study 1. In fact, all groups now perform above chance on the task of predicting species kind as measured by a preplanned t-test; four-year-olds, $t(15)=2.24$, $p<.05$; five-year-olds, $t(15)=4.39$, $p<.001$; six-year-olds, $t(15)=15.00$, $p<.001$; seven-year-olds and adults were both at ceiling. It appears that something in the property task of Study 2 improved the performance of children in the kind task. Why this should be is unclear. One difference between the studies is that Study 2 involved even greater emphasis on the distinction between the two parent-offspring relationships than Study 1 did, due to the repetition of the birth/nuture contrast through all twelve property items. Perhaps this greater emphasis helped children clarify exactly what the relevant issue was and so boosted their performance.

Justifications by Kind Judgments

Justifications were coded in order to determine whether the property task had the effect of focusing or clarifying children's explanatory knowledge or factual/predictive knowledge about the role of birth in species kind determination. If children were somehow coaxed by the property task into understanding or revealing previously untapped explanatory knowledge about species kind origins, then the kind pattern groups should show an increase in children expressing the origins explanation relative to Study 1. If on the other hand, it succeeded in focusing children only on the predictive power of the birth relationship, there should be an increase in the number of children justifying birth parent kind judgments with non-origins explanations. If it had no effect on children's kind judgments, increasing neither their explanatory nor predictive knowledge of birth, then the overall distribution of children in the pattern groups should be similar to that in Study 1. Justifications were coded into the same categories used in Study 1. Figure 8 reports the percentage of explanations within each kind judgment for each age.

Because of the success in producing birth parent kind judgments, there were only seven adoptive parent judgments in all of Study 2, producing too few explanations to discuss. Nonetheless, a comparison of Figure 8 with Figure 2 of Study 1 reveals some interesting differences. In both figures, we accept that the percentage of origins explanations are only approximations of subjects' belief in an inheritance theory of species kind. This was true in Study 1 because the numbers included repetitions of probes for the same explanation which presumably leads some subjects (particularly adults) to give less explicit explanations the second time

FIGURE 8. Study 2 percentages of subjects in each pattern group by age (the number in parentheses is the absolute number of children).

Age	4 yrs		5 yrs		6 yrs		7yrs		Adults	
Judgment Type	B	A	B	A	B	A	B	A	B	A
Origins	42	0	18	0	37	0	67	-	69	-
Intrinsic Nature	8	0	55	0	27	0	13	-	12	-
Mother's Kind	8	0	0	0	18	0	20	-	0	-
Nuture	0	0	0	50	0	100	0	-	0	-
Other/Don't Know	42	100	27	50	18	0	0	-	19	-

around for pragmatic reasons alone. This was demonstrated in Study 1 by the increase in adults credited with the inheritance theory of species kind if the criterion was adjusted to reflect individual patterns rather than group patterns. The adult data reflects this pragmatic sensitivity here in Study 2. None of the other ages reflected this directly in Study 1, but presumably it could be operating here in Study 2 all the same, thereby underestimating subjects reliance on origins belief.

On the other hand there was also some concern in Study 1 that the explanation data overestimated younger children's knowledge by giving them credit for justifications that could have been straight recalls of salient parts of the task, like the comprehension probes. This was also evident in Study 1 when individual patterns were analyzed and we saw that some of the younger children both made adoptive parent kind judgments and used birth explanations, belying any deep understanding of the role of origins in species kind determination.

All of these arguments hold for the results in Figure 8 as well. Unfortunately, in Study 2 subjects only had one opportunity to make their judgments and justify them, so we have no way of adjusting for pragmatics (underestimation) or consistency (overestimation). Nonetheless, both the adult and seven-year-old data and to a large extent the six-year-old data replicate Study 1. We therefore feel relatively confident that the six- and seven-year-olds (as well as the adults) were largely uneffected by the property task. The five- and four-year-old data, however, are very different from the results of Study 1. The five-year-olds in Study 2 were overwhelmed by intrinsic nature explanations, to the detriment of the origins explanations. Either they were even more effected by pragmatics than the older children (which we have no reason to believe they were) or the property task had the effect of eliciting a strong essentialist bias for this age. This belief in essentialism somehow interfered with or blocked the already infrequent use of birth as a justification for species kind. The fact that this could happen suggests that the knowledge of birth at this age is probably only factual knowledge which has not been embedded in a causal theory. This suggests the number of children at this age with a true inheritance theory of kind identity is very small indeed. It also suggests that the four-year-olds who did justify their judgments with birth do so with very little explanatory understanding, relying instead on simple factual knowledge. Interestingly, notice that the four-year-olds did not even use intrinsic nature explanations, suggesting that even that theory is not present as early as you look.

This justification data do seem to answer the question of what effect the property task in Study 2 had on the kind task. It does not appear that it helped clarify the relevance of the birth relationship in the stories in terms of its *causal* implications. Rather it appears to have focused children potentially as young as four, on the *predictive* power of the birth relationship with respect to kind identity. This is consistent with everyone's intuitions that certainly five-year-olds and probably most four-year-olds know that dogs do not give birth to cats. This argument presupposes that that knowledge was already in place for the children, and that the property task in Study 2 served only to focus children on the relevant aspects of the story for the required inference. It does not argue that the property task taught the children the predictive power of the birth relationship for kind membership. In fact there was nothing in the property task that provided any additional information beyond that provided in the kind task. The fact that the property judgments effected children's predictive and not explanatory knowledge of the role of birth is consistent with the notion that explanatory knowledge is hard to come by and not easily taught.

Conclusions

Property Origins: The Inheritance vs The Essentialist Theory

We found no evidence that children have a biological inheritance theory of the origin of properties any earlier than that suggested by Solomon et al. In fact, children in these studies were significantly behind those in Solomon et al with respect to the inheritance of individual properties of animals. They failed to reliably make the differentiated adult judgments of property type even at the age of seven, an age where Solomon et al found nearly ninety percent success on a within-species task. Rather it seems that the majority of children at these ages are relying on an earlier non-domain specific essentialist theory of property origins to explain kind resemblance.

It also seems a puzzle that fully two-thirds of seven-year-olds understand the origin of species kind as shown in both Study 1 and 2, and yet only thirty-eight percent succeed on the species property task. Nowhere did we predict that they would be worse on the seemingly intermediary task of cross-species property inheritance than they were on the species kind task. In retrospect we think this probably has to do with the existence of the early essentialist theory of property origins which covers the origin of species properties but not of species kind. This conversely allows questions of species kind origin to be subsumed by the inheritance theory more easily and earlier than questions of species properties are. Similarly, children may perform best on the Solomon et al within-species property task, specifically because it does not contradict any predictions made by the essentialist theory. The early essentialist theory covers kind resemblance not family resemblance. In a within-species task the inheritance theory generates inferences which are consistent with the essentialist species theory, given that the adoptive parent is of the same species. Trouble arises when the child is asked about the individual properties of one species given that it is raised by another species, because now these two theories generate conflicting inferences.

On the interpretation that children first have an essentialist theory of property origins and only later an inheritance theory, it should not be surprising to find that it takes quite a long time to work out all of the implications of an inheritance theory such that it works even in cross-species cases. This interpretation may explain the apparently anomalous results of Study 2 in which we had Differentiated children who showed the adult pattern but still justified it with intrinsic nature explanations, something the adults never did. This result suggested that even the Differentiated children were not all in agreement about whether the question, "Why does the baby have a brown nose?" was covered by an inheritance theory, and thus answered by "because his birth mother had a brown nose" or an essentialist theory, and thus answered by "because all horses have brown noses".

Whether the essentialist theory, as reflected by intrinsic nature explanations, is ever used as a specific *biological* theory about the origin of physical properties in the way that the inheritance theory is is still ambigous from these results. If children who produce the differentiated pattern of property judgments do so with a reliance on an essentialist theory of property origins in combination with some predictive knowledge about the role of birth in species kind origins, then we would conclude that those children had a biological essentialist theory. Although suggestive, our explanation data alone do not provide sufficient evidence to argue for or against this possibility. Without a doubt the major usage of the essentialist explanation came from children who gave independent evidence of non-domain specific reasoning in the form of birth bias judgment patterns.

For all of the Birth bias children, neither the use of birth nor intrinsic nature explanations reflect biological theories in the sense that those of the Differentiated children did. Because again, in order for a reasoning principle to count as a biological principle it must display domain-specificity, a characteristic which neither of these principles do for birth bias children.

The conclusion that the majority of children hold an essentialist causal theory of property origins well into the seventh year is consistent with other results in the literature. Gelman and Welman (1991) suggest that preschooler's appreciate that featureless babies will develop the features of their species despite conflicting environmental influences. Similarly Springer and Keil (1991) showed that nearly all six- and seven-year-olds and half of preschoolers believe that an animal's color is determined by something inside the animal rather than outside. Interestingly notice that Springer and Keil's developmental increase between five and six parallels our increase in intrinsic nature explanations and birth bias patterns from four to five, suggesting that even the essentialist theory for property origins is not present all the way down.

Species Kind Origins:

Factual and Predictive Knowledge vs. Explanatory Theories

With respect to when children construct an inheritance theory of the origins of species kind, the evidence is less clear. We have some evidence that children have begun to learn something about the role of birth, at least with respect to species kind, earlier than when they have constructed a complete explanatory theory. That is, at the very least they have learned some factual knowledge upon which they can base simple kind predictions. Evidence of this non-explanatory sensitivity to the birth relationship showed up in the form of disproportionately more birth parent judgments than adoptive parent judgments in both kind tasks of Study 1 and Study 2. In Study 2 the predictive knowledge of the role birth plays was potentially in evidence as early as the age of five. The existence of such non-explanatory knowledge would be consistent with the results of Bernstein and Cowan (1975) and Goldman and Goldman (1982). Both studies report that preschoolers are likely to know the facts about where babies come from but that they fail to embed those facts into an explanatory framework of reproduction with causal implications. Bernstein and Cowan offer the following example (p.86);

B&C: How did the baby happen to be in your Mommy's tummy?

Child: It just grows inside.

B&C: How did it get there?

Child: It's there all the time. Mommy doesn't have to do anything. She waits until she feels it.

B&C: You said the baby wasn't in there when you were there.

Child: Yeah, then he was in the other place. in . . . in America.

B&C: In America?

Child: Yeah, in somebody else's tummy.

B&C: In somebody else's tummy?

Child: Yeah, and then he went through somebody's vagina, then he went in, um, in my Mommy's tummy.

B&C: In whose tummy was he before?

Child: Um, the I don't know, who his, her name is. It's a her.

This response is taken to show that children often know that babies come from mommies tummies before they have grasped the notion that this is part of an important causal story in which babies are *created* in mommies tummies.

With respect to the explanatory understanding, as a group children seem to have mastered the concept by the age of seven. This is supported by the two-thirds of seven-year-olds in both Studies 1 and 2 who showed the inheritance theory. Thirty to forty percent of four-, five- and six-year-olds also demonstrate the inheritance theory of kind identity. These results are perfectly in line with the Solomon et al results, suggesting that the two achievements are part of the same understanding of inheritance, based on birth as a causal mechanisms.

The conclusion that the explanatory role of birth in concepts of species kind is understood late is consistent with other work in the literature. Keil (1993) reports an interesting study where before the fourth grade children are unwilling to infer that animals with completely different origins and developmental histories must be different kinds of animals. So for instance he describes two animals. One of the animals is hatched from an egg with lots of long fur and is green and yellow during development. The other animal is born alive with no hair and is bright red during development. One animal grows up in tree tops, the other sleeps under leaves. The children are then shown pictures of the two grown animals in which they look identical. The question is are they the same kind of animal. According to Keil almost all kindergartners and close to eighty percent of second graders claim that they are the same kind of animal. Even forty percent of fourth graders still claim that they are the same. As Keil himself puts it, young children just do "not attach much importance to origins for individuating kinds at the level of species, even though this seems so basic to adult concepts in biology." Although this was not directly an inheritance study, the failure of these children is consistent with our claims.

Keil also has results from transformation tasks (1989), where children claim that if a doctor operates on an animal so that it has the characteristic traits of a different species, preschoolers and even first and second graders will report that the animal's species identity has changed. These results demonstrate that not only are young children somewhat oblivious to the origin of the animal itself in consideration of its species identity, neither are they as concerned with the origin of the animal's properties as with the properties themselves.

Another study by Callanan, Perez, McCarrell, and Latzke (1992) suggests yet another limitation on preschoolers ability to relate origins (as reflected by being a baby) and species kind. When asked to choose which of two animals is the baby of a particular mother, preschoolers choose a small 'babylike', but different species animal over a large 'unbabylike', but same species animal. In this case, the simple factual knowledge that dogs have dogs and not cats failed. This is understandable if it is only a piece of predictive knowledge and not part of a causal story. In this case, the child's belief is better read as 'all things being equal, dogs have dogs and not cats.' This belief is then overriden by a stronger belief that babies are small. By the age of seven, children began making choices based upon species kind rather than baby-likeness. This result again, while not directly tapping inheritance judgments, is consistent with the notion that young children have not integrated their concepts of species kind with their concepts of animal origin (if indeed they have a concept of animal origin).

The conclusion to draw from all of these results is consistent with ours. It takes a long time for children to construct an explanatory theory of biological origins which can carry the inferential load of all of these tasks, involving species kind and property judgments, reproduction, inheritance, and family resemblance.

This point generalizes to the claim that there are periods in development where children have learned individual facts but have not yet analyzed them in terms of their causal explanatory roles. In the normal course of development the construction of these explanatory theories follows so closely upon the acquisition of factual knowledge, that unless we look closely, we do not see one without the other. The claim that factual knowledge is in some sense prior to explanatory knowledge, seems not only reasonable, but necessary for a complete understanding of theory construction. The questions which theories are constructed to explain must arise from somewhere. And the facts which theories are constructed out of, must be learned at some point.

Overall, these results show that as a majority young children come to understand the biological inheritance of species kind around the age of seven, the same time they understand the inheritance of individual properties. Individual children, however, can show evidence of an origins theory of species kind as early as we looked, which was four years. Understanding the causal role of birth in the origins of an animal's properties as both important and distinct from the animal's species essence seems to take children quite a long time to work out, an accomplishment that is achieved somewhere between the ages of seven and adulthood. In addition we found tentative evidence that children learn the facts about the birth relationship among family members such that they can use it to predict species kind, well before they can use it to explain species kind. This opens the possibility that knowledge of the facts of birth is one of the cornerstones upon which young children construct of a theory of biology.

BIBLIOGRAPHY

Bernstein, A. and Cowan, P. (1975). Children's concepts of how people get babies. *Child Development*, 46, 77-91.

Bromberger, S. (1992). *On what we know we don't know: Explanation, theory, linguistics, and how questions shape them.* Chicago, IL: University of Chicago Press.

Callanan, M., Perez, D., McCarrell, N., and Latzke, M., (1992). Children's concepts of baby animals. *Paper presented at APS.*

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Carey, S. (1988). Conceptual differences between children and adults. *Mind and Language,* 3, 167-181.

Carey, S. and Spelke, E. (in press). Domain specific knowledge and conceptual change. In L.A. Hirschfeld and S.A. Gelman (Eds.), *Domain Specificity in Cognition and Culture.* New York: Cambridge University Press.

Carey, S., Johnson, S.C., and Levine, K. (1993). Conceptual structure of adults/adolescents with Williams syndrome. *Poster at SRCD conference,* New Orleans.

Chomsky, N. (1980a). *Rules and Representations.* New York: Columbia University Press.

Chomsky, N. (1980b). Rules and Representations. *Behavioral and Brain Sciences*, 3, 1-61.

Gelman, S.A. (1988). The development of induction within natural kind and artifact categories. *Cognitive Science*, 20, 65-90.

Gelman, S.A. and Markman, E.M. (1987). Young children's inductions from natural kinds: The role of categories an dappearances. *Child Development*, 58, 1532-1541.

Gelman, S.A. and Wellman, H.M. (1991). Insides and essences: early understandings of the nonobvious. *Cognition*, 38, 213-244.

Goldman, R. and Goldman, J. (1982). How children perceive the origin of babies and the roles of mothers and fathers in procreation: A cross-national study. *Child Development*, 53, 491-504.

Gopnik, A. and Wellman, H.M. (1993). The theory theory. In L. Hirschfeld and S. Gelman (Eds.) *Domain specificty in cognition and culture.* New York: Cambridge University Press.

Guntheil, G. and Rosengren, K. (1993). The more things change the more they stay the same: Children's understanding of growth and identity, *Paper presented at SRCD*, New Orleans, LA.

Hirschfeld, L.A. (in press). The child's representation of human groups. In D. Medin (Ed.) *The psychology of learning and motivation: Advances in research and theory*, 30, San Diego: Academic Press, Inc.

Johnson, S.C., Solomon, G.E.A., and Carey, S. (1994). Why dogs have puppies and cats have kittens: Young children's understanding of species kind and the inheritance of properties. this volume.

Karmiloff-Smith, A. (1988). The child is a theoretician, not an inductivist. *Mind and Language*, 3, 183-193.

Keil, F.C. (1989). *Concepts, kinds, and cognitive development.* Cambridge, MA: Bradford Books.

Keil, F.C. (1992). The origins of an autonomous biology. In M.R. Gunnar and & M. Maratsos (Ed). *Modularity and constraints in language and cognition: the Minnesota symposia on child psychology,* 25, Hillsdale, NJ: Erlbaum.

Kitcher, P. (1988). The child as parent of the scientist. *Mind and Language,* 3, 217-227.

Leslie, A.M. (in press). ToMM, ToBy, and Agency: core architecture and domain specificity. Domain specific knowledge and conceptual change. In L.A. Hirschfeld and S.A. Gelman (Eds.), *Domain Specificity in Cognition and Culture.* New York: Cambridge University Press.

Locke, J. (1894/1959). *An essay concerning human understanding,* Vol. 2. New York, NY: Dover.

Medin, D.L. (1989). Concepts and conceptual structure. *American Psychologist,* 44, 1469-1481.

Medin, D. and Ortony, A. (1989). Psychological essentialism. In S. Vosniadu and A. Ortony (Eds.) *Similarity and analogical reasoning.* Cambridge, UK: Cambridge University Press.

Perner, J. (1991). *Understanding the representational mind.* Cambridge, MA: MIT Press.

Salmon, W. (1989). *Four decades of scientific explanation.* Minneapolis, MN: University of Minnesota Press.

Smith, C., Carey, S., and Wiser, M. (1985). On differentiation: a case study of the development of the concepts of size, weight, and density. *Cognition,* 21, 177-237.

Solomon, G.E.A., Johnson, S.C., Zaitchik, D., and Carey, S. (1994). Like father, like son: Young children's understanding of how and why offspring resemble their parents. submitted for review.

Spelke, E. (1991). Physical knowledge in infancy: Reflections on Piaget's theory. In S. Carey and R. Gelman (Eds.) *Epigenisis of Mind: Essays on Biology and Cognition*, Hillsdale, NJ: Erlbaum.

Springer, K. (1992). Children's beliefs about the biological implications of kinship. *Child Development*, 63, 950-959.

Springer, K. and Keil, F.C. (1989). On the development of biologically specific beliefs: The case of inheritance. *Child Development*, 60, 637-648.

Springer, K. and Keil, F.C. (1991). Early differentiation of causal mechanisms appropriate to biological and nonbiological kinds. *Child Development*, 62, 767-781.

Vosniadu, S. and Brewer, W.F. (1992). Mental models of the earth: a study of conceptual change in childhood. *Cognitive Psychology.*

Wellman, H.M. and Gelman, S.A. (1992). Cognitive development: foundational theories of core domains. *Annual Review of Psychology*, 43, 337-375.

When the Facts are not Enough:
Conceptual Change in People with Williams Syndrome

Recently the attention of researchers has turned to the study of intuitive theories as a way to understand both the representation and acquisition of conceptual knowledge. This research program holds that peoples' knowledge about the world is organized into domain-specific explanatory theories of which framework theories make the deepest cuts (Wellman and Gelman, 1992; Carey, 1985; Kitcher, 1988; Murphy, 1993). It is framework theories that define the ontology, phenomena, and explanatory principles which we use to understand and reason about the world. And it is framework theories that are the foundation upon which the child's understanding and knowledge of the world is built. On this view then, one of the challenges that children face is to discover and build the theories held by the adults in the culture in which they live. The challenge of the cognitive developmentalist is to characterize and explain the developmental course through which children come to hold these theories. The pursuit of this goal is well underway and making considerable progress in the domains of theory of mind, biology, matter, contact mechanics, and cosmology (Wellman and Gelman, 1992; Gopnik and Wellman, 1993; Carey, 1985, 1988, 1991; Smith, Carey, and Wiser, 1985, Karmiloff-Smith, 1988; Spelke, 1991, Vosniadu and Brewer, 1992).

The study of theory-building itself covers many distinct issues, one of which is the nature of conceptual change. Conceptual change is a notion taken from the philosophy of science literature (Kuhn, 1962; Kitcher, 1988). It refers to the reorganization and reanalysis of individual concepts which occur when one theory is replaced by a second, *incommensurable* theory. Cognitive developmentalists use the more restricted notion of *local* incommensurability (Kuhn, 1982; Kitcher, 1988; Carey, 1988, 1991). Incommensurability in general refers to cases where in two languages (L1 and L2) or two theories (T1 and T2), there exists no mapping between concepts in the two theories. The matter can be framed in terms of reference fixing. Incommensurability occurs when methods of fixing the referent (definition, ostension, inferential role) of a concept in T1 pick out different entities (theoretical or otherwise) than the methods of T2 for the 'same' concept. (The reader is referred to Carey (1988, 1991) and Kitcher (1988) for more detailed discussion of the referential potential of terms and concepts.)

There are several different ways in which concepts can change in the face of incommensurabilities. A detailed analysis of these changes is given by Carey (1988), of which the following is a brief synopsis. Carey describes several examples of types of changes from the history of science, including differentiations (such as occurred when Galileo differentiated *average* from *instantaneous velocity*), coaelescenses (such as occurred when Aristotle's distinction between *natural* and *violent motions* was abandoned) and the reanalysis of a concept's kind (such as the Newtonian reanalysis of *weight* from a property of objects to a relationship between objects.)

Examples of conceptual changes in individual development are documented in the psychological literature as well. Conceptual changes occur in the domains of matter, cosmology, and biology, to name a few. Several conceptual changes occur along the developmental path to an adult theory of matter. Young children come to differentiate a previously undifferentiated concept of *air* and *nothingness* (Carey, 1991). Later, they come to reanalyze the undifferentiated concept of *weight* along the dimensions of mass and density (Smith, Carey, and Wiser,1985). In the domain of cosmology, Vosniadu and Brewer (1992) document a dramatic shift in the preschooler's conception of the earth based on a reanalysis of a directional reference framework and the concepts *up* and *down*.

In the domain of intuitive biology, the literature contains several well-documented examples of conceptual changes. These include a the differentiation of the child's concepts of *not-alive* into the adult's concept of *dead, inanimate,* and *unreal* (Carey, 1985, Laurendeau and Pinard, 1962; Piaget, 1929) and the reanalysis of *death* from a behavioral interpretation to include a notion of the collapse of a biological machine (Koocher, 1974, Nagy, 1953; Carey,1985. It also includes the shift in the concept *person* from prototypical animal to one-among-many (Carey, 1985) and of *baby* from small, helpless animal to reproductive offspring (Carey, 1985). The concept of *living thing* is formed out of a coalescence of the concepts of animal and plant. The core features of the concept *species* kind shift away from physical characteristics toward origins of the animal (Keil, 1989; Johnson, Solomon, and Carey, 1994). The concept of *family* becomes differentiated into separate concepts of biological and social family (Solomon, Johnson, Zaitchik, and Carey, 1994). The successful achievement of each of these conceptual changes can be diagnosed by existing tasks in the literature. For each task, normal adult knowledge is incommensurable with the child state and cannot be reached without conceptual reorganizations of the child state.

Williams Syndrome

WS is a neurodevelopmental disorder of genetic origin (Morris, 1994) which typically results in mental retardation as well as a variety of other physical problems including heart defects, metabolic problems of calcium and calcitonin, failure to thrive, hyperacusis, and characteristic facial and dental features (Williams, Barrett-Boyes, and Lowes, 1962; Jones and Smith, 1975; Udwin and Yule, 1991). Neuroanatomical studies of WS reveal no localized lesions in the neocortex, although there is evidence of reduced cerebral volume in general, together with unusual preservation of neocerebellum (Jernigan and Bellugi, 1990). People with Williams syndrome also have the reputation of verbal loquacity and hypersociability (Jones and Smith, 1975) and are often characterized as displaying cocktail party syndrome; the propensity to talk prolifically about nothing. Researchers in language and cognition have documented dissociations between major cognitive domains such as language and visuospatial processes and between language and conceptual processes (Bellugi, Bihrle, Neville, Jernigan, and Doherty, in press). Within individual domains, researchers have documented dissociations within morphology and syntax (Karmiloff-Smith and Grant, 1993; Bromberg, Ullman, Marcus, Kelly, and Levine, 1994), and between face recognition and other aspects of spatial and visual organization and memory (Birhle, Bellugi, Delis, and Marks, 1989).

With respect to the dissociations between language and cognition, Bellugi and her colleagues documented severe conceptual reasoning impairments with respect to syntactic and lexical abilities. They found severe impairments in the ability to formulate definitions, make similarity judgments, and conserve number and quantity in Piagetian conservation tasks. These same subjects successfully demonstrated mastery of syntactic abilities such as reversible passives and embedded clauses as well as the vocabularies of normal eight-and-a-half-year-olds. In addition, these subjects who in many respects had the higher-order conceptual abilities of preschoolers had remarkable category fluency abilities, sometimes at par with their chronological age. Results like these show a dramatic dissociation between language abilities on the one hand and conceptual abilities on the other hand.

Other research documents preserved conceptual knowledge as well. Levine (1993) assessed a group of twenty WS children using the Kaufman Battery and found that among other things WS subjects had significantly better performance on tasks involving general information and vocabulary than predicted by overall performance. This result is consistent with another example given by Bellugi et al to demonstrate the dissociation between visuospatial skills and language abilities in people with WS. Bellugi, et al. published a dramatic example of a WS adult who was asked to draw and describe an elephant. Her description of the elephant is reproduced here.

> "And what an elephant is, it is one of the animals. And what the elephant does, it lives in the jungle. It can also live in the zoo. And what it has, it has long gray ears, fan ears, ears that can blow in the wind. It has a long trunk that can pick up grass, or pick up hay... If they're in a bad mood it can be terrible. If the elephant gets mad it could stomp. It could charge. Sometimes elephants can charge, like a bull can charge. They have big long tusks. They can damage a car...It could be dangerous. When they're in a pinch, when they're in a bad mood it can be terrible. You don't want an elephant as a pet. You want a cat or a dog or a bird....."

This and other similar examples certainly display the general fluency and verbosity of people with WS, but it also suggests a certain preservation of conceptual knowledge. The description given by this subject contains a great deal of conceptual content. Despite her inability to produce a picture which could be reliably recognized as an elephant, she described at length what an elephant is, what an elephant looks like, where elephants are found, and how elephants act.

These interesting results led us to ask the following questions. Is it possible that WS subjects might demonstrate unusual dissociations *within* their conceptual systems. In the course of normal development children accumulate facts and reorganize them into explanatory theories in tandem. This constant two-way process of theory-building makes it difficult for researchers to study each aspect of the process independently. Given the apparent lexical and categorical abilities of people with WS, in the face of impaired reasoning, the possibility exists to see a distinction between these aspects of conceptual development which is relatively hidden in normal development. The likelihood that conceptual reorganization of knowledge requires higher-order reasoning abilities (Nersessian, 1992; Carey and Spelke, in press), implies that people with WS may show no evidence of the normal conceptual changes seen in development, despite being relatively good at acquiring isolated bits of information. The documentation of a dissociation like this would provide independent confirmation for the theoretical distinction between learning involving conceptual change and the more straightforward learning involved in the accumulation of facts. It would also provide a new avenue through which to study these two processes independently in order to characterize the parameters of each.

The Study

These questions led us to construct the following hypothesis. WS subjects are relatively impaired in processes which are necessary for the reorganization of knowledge entailed in conceptual change, while simultaneously being relatively unimpaired in processes which allow the accumulation of knowledge which does not entail conceptual change. This impairment should prevent people with WS from achieving the conceptual changes which occur in normal development and therefore from constructing the intuitive theories of normal adults, despite relative success in the construction of productive categorical knowledge.

We approached this hypothesis by designing two sets of tasks which diagnose categorical knowledge and conceptual achievement within the domain of an intuitive biology. The tasks were assigned to each set on the basis of whether or not normal adult *performance* (as opposed to normal adult knowledge) *requires* conceptual change, that is conceptual knowledge which is incommensurable with the knowledge of normal preschoolers. The first set, called the Enrichment set, included tasks designed to assess the quantity and organization of simple, animal-based knowledge. Normal adult performance on these tasks, while more elaborated, productive, and detailed than a young child's, is nonetheless commensurable with a young child's knowledge. This is possible because the category of animal picks out the same extension for both very young children and adults (Mandler, 19xx; Massey and Gelman, 1988), even though adults have undergone a theoretical shift on related concepts. The second set, called the Conceptual Change set, included tasks designed to investigate their understanding of concepts which *are* implicated in conceptual changes in normal development; *alive* , *death, people-as-animals* , *living thing,* *and species.* That is, the normal adult concepts denoted by these terms are incommensurable with the young child's concepts denoted by the same terms. The presumption for these tasks is that adult performance is evidence of having achieved the conceptual changes entailed by the adult theory.

We wanted to do everything possible to insure that we did not underestimate the knowledge and ability of the WS subjects. Therefore, our overall strategy for testing this hypothesis involved addressing three issues deemed prerequisites for interpreting the ultimate results. These were 1) justifying the choice of intuitive biology as the content domain to be examined, 2) setting subject inclusion criteria so as to maximize WS subjects' chances of success, and 3) selecting appropriate control groups. Because of their importance these issues will be discussed in detail before continuing to the actual experiments.

Domain selection

There were three major criteria to satisfy in picking our domain. First, we wanted to avoid any domain which might require visuo-spatial reasoning. This was to minimize the chance that any failure on the part of our WS subjects is due to possibly irrelevant, non-conceptual issues. Intuitive biology satisfies this criteria more cleanly than either number or physical reasoning do. Theory of mind is another possibility not involving visuo-spatial reasoning, but its status as a constructed theory is controversial.

Second, we wanted to use a domain which WS subjects have ample exposure to and interest in. Again, intuitive biology is a good candidate. Intuitive biology is acquired in normal development with little or no formal training. Exposure to daily life in a biological body and contact with other bodies seems sufficient evidence with which to build an intuitive biology. WS subjects are, if anything, privy to more than the average biological evidence thanks to their own frequent medical needs. In addition, anecdotal evidence suggests that the typical WS subject is in fact greatly interested in animals. Motivation to understand the animal kingdom seems likely if not guaranteed.

Finally, we wanted to investigate WS subjects' knowledge achievements in a domain where we already know something of what the normal developmental picture looks like. This picture is largely available in the domain of intuitive biology (Carey, 1985; Laurendeau and Pinard, 1962; Keil, 1989; 1992; Koocher, 1974, Nagy, 1953), providing a wealth of well-documented conceptual changes which occur in normal development.

WS subject selection

Our strategy in selecting a group of WS subjects is similar to that used in picking a domain. We wanted to maximize the chance that the subjects we chose would be able to succeed on the tasks we gave them. Therefore for the purposes of assessing biological knowledge, we selected only WS subjects who were beyond the normal age for the conceptual changes involved in at least one of *either* mental or chronological age. In the domain of intuitive biology, the conceptual changes we sought occur generally between the ages of four and eight, varying somewhat depending on the task and the child. Therefore, we restricted our inclusion of WS subjects to only those who have *either* a chronological age or a mental age of at least 10 years 0 months.

The logic of matching controls and specific predictions

The purpose of our matched normal control group is of course to insure that any dissociations found within the performances of WS subjects are not also found in normal development. There are two aspects to this problem, one based on an analysis of individual performances and the other based on the measure of matching. In this section we will discuss the selection of a matching tool, the logic of individual matching, and a potential problem of matching with a measure other than those directly involved in the question at hand.

A central issue concerning subject selection concerns determining the appropriate group against whom to compare the WS subjects' performance. We have chosen as our matching measure the Peabody Picture Vocabulary Test-Revised (PPVT-R) (Dunn and Dunn, 1981). Note that this is a measure of verbal mental age only. The PPVT-R is a receptive vocabulary task which places minimal demands on the subject. For each item the subject is read a word and shown a set of four line drawings. The subject's task is to pick which of the four pictures best depicts the word. The PPVT-R is normed on 200,000 subjects and provides an estimate of the subject's verbal mental age. For subjects up to thirty-four years old it also provides a standardized score which correlates roughly with verbal IQ. The motivation behind the use of a solely verbal measure is the following; the tasks we are using to diagnose conceptual knowledge are all verbally loaded tasks, requiring the subject to be able to interpret verbal material (narratives and verbal questions) and produce verbal responses (judgments and explanations). A matching tool which includes a measure of spatial abilities, such as a full-scale IQ score, will likely underestimate the abilities against which we are interested in comparing their conceptual change achievements, that is , the general acquisition of vocabulary and information. The reason for picking the PPVT-R in particular is that its receptive nature minimizes the possibly unrelated issues of word retrieval and anxiety prevalent in WS (Dilts, Morris, and Leonard,1990; Udwin and Yule, 1991.) Matching a normal control subject to a WS subject requires administering the PPVT-R to normal subjects and selecting those who are within one standard deviation of the standardized score for both 1) the average for their own chronological age and 2) the WS subject's mental age.

The issue with respect to individual performance is the following. We assume that levels of achievement across tasks are normally correlated within individuals, however, in the domain of biology this has not been documented. We know that as a group, ten-year-olds may succeed on two different tasks with an eighty percent success rate, but we do not know that the twenty percent who fail on one task are the same twenty percent who fail on the other. It is possible that performance on one task does not necessarily predict performance on the other task, even though group performance for that age is equivalent on the two tasks. In this case it would be unremarkable if the performances of individual WS subjects also failed to predict each other.

With this point in mind our strategy is the following. Each WS subject was assigned his or her own normally-developing control subject of matched mental age. Each task analysis was conducted on the basis of these matched pairs. Subjects received a single score for overall performance on each task. This coding was based on a conceptual analysis of what constitutes success on that particular task, as supported by the literature. For each task both parametric (paired t-test) and non-parametric (Wilcoxon signed-ranks test) comparisons were made, comparing performance of the WS subjects with performance of their matched controls. Based on our hypothesis that WS subjects are impaired on tasks requiring conceptual changes relative to matched controls, but 'normal' on tasks not requiring conceptual changes, we made a one-tailed prediction. We predicted that on each of the Enrichment tasks the WS subjects would not be significantly different than their matched controls, but that on each of the Conceptual Change tasks they would be significantly worse.

Another issue with respect to the measure of matching is important to consider. If we do find a dissociation between the task sets in WS subjects relative to their matched controls, we need to know that it is in fact a dissociation between the two sets of conceptual tasks and not between the conceptual tasks in general on the one hand and vocabulary, our matching measure on the other. Suppose for instance, that the tasks in the Enrichment set are normally mastered at an age earlier than the typical mental age of our matched group. If both the WS and matched controls are at ceiling on the Enrichment tasks, so might be younger normally-developing children. That would leave open the possibility that there are younger normal children who show the same 'dissociation' in conceptual achievement that the WS subjects show, since younger children are also less likely to succeed on the Conceptual Change tasks. The existence of this 'dissociation' in normal development would allow the possibility that some concepts may simply take longer to acquire than others for everybody. Though this state of affairs would not disprove the claim that the dissociation is specifically a dissocation between two distinct learning processes, it would certainly undermine it.

Therefore we required a secondary control group of children at an age slightly younger than the average of the matched group. If a dissociation found in WS subjects is indicative of a younger age group than that selected by the PPVT-R, then the younger control group should pattern with the WS group. Nonetheless we predicted that the younger group's pattern of results would be different from the WS group. There are several possible ways in which the two groups' patterns can differ. Presuming that the WS subjects are at or near ceiling on the Enrichment tasks and at floor on the Conceptual Change tasks, the younger control group can differ by being either at floor on both sets, at ceiling on both sets (in which case we would need to find an even younger group above floor, but not yet at ceiling), or they can succeed on some tasks in each set, and fail on some tasks in each set. If we perform a two-tailed t-test between groups, the only result which would reflect the same dissociation would be one of statistical equivalence on all of the tasks in both sets.

Subjects

• *WS* Ten subjects with Williams syndrome were recruited from the New England Williams Syndrome Association and Boston's Children's Hospital. They ranged in chronological age (CA) from 10 years 6 months to 29 years 9 months, with a mean CA of 20 years 4 months. They ranged in mental age (MA) from 6 years 10 months to 12 years 7 months, with a mean MA of 9 years 11 months. Diagnosis of Williams syndrome was confirmed by doctors at Boston's Children's Hospital. Subjects were paid for their participation. Testing occurred in two or three sessions either at the hospital or the subject's home.

• *Matched controls* Ten normally-developing control subjects were recruited from the Cambridge, MA public school system and a summer camp for the children of MIT employees. They ranged in chronological age from 6 years 6 months to 12 years 7 months, with a mean CA of 9 years 4 months. They ranged in mental age from 7 years 6 months to 14 years 7 months, with a mean MA of 10 years 6 months. Controls were tested at their schools also in two testing sessions.

• *Younger controls* Eleven younger controls were recruited from the Cambridge, MA public school system. They ranged in chronological age from 5 years 5 months to 9 years 3 months, with a mean CA of 6 years 6 months. In addition some normative data from other sources in the literature is used and cited as such.

Materials - Descriptions of Task and Scoring Methods

Although all of the tasks we used derive from tasks found in the literature, they are not standardized tasks. Therefore we describe the general logic behind the design and scoring of each task. For more thorough discussion of the issues involved in each task, the reader is referred to the relevant literature.

Enrichment Tasks

This set of tasks included attributions of bodily properties to animals and inanimate non-living objects, the projection of a novel property taught on people, and category fluency. The presumption is that normal adult performance as reflected by these tasks does not entail conceptual change. In each case, it is logically possible for the adult state to be achieved through the enrichment of early categorical knowledge. In other words, adult-like performances on these tasks reflect knowledge which is not *necessarily* incommensurable with the knowledge of young children reflected by these tasks.

• *Attribution* This is an inductive inference task modeled on those reported in Carey (1985). The subject is shown a picture of an object and asked a series of simple yes/no questions about the object. Our version of the task uses a total of seven objects from the categories of animals and non-living inanimates. The objects are people, dogs, birds, worms, computers, the sun, and ragdolls. For each object, subjects are asked a series of yes/no questions including four about possible animal properties of the object. The four animal properties are 'breathes', ' has a heart', 'hears', and 'has babies'. These questions are intermixed with filler questions designed to provide assurance that the task demands are within the capabilities of the subjects. Fillers include simple questions like 'do dogs live in refrigerators?' Fillers are worded such that the correct answer is sometimes 'yes' and sometimes 'no' in order to avoid setting up response biases.

Normal performance on this task is characterized by two main effects (Carey, 1985; Inagaki and Hatano, 1987). First, normal subjects at all ages studied are able to use the distinction between animals and non-animals to constrain their inferences. It is seldom the case that subjects of any age attribute animal properties to non-animal entites (ignoring for the moment, the category plants), including objects which they independently rate as highly similar to people such as mechanical monkeys and ragdolls. Second, there are developmental effects on the pattern of animal property attributions *within* the category of animal. Young children attribute animal properties with decreasing frequency as the object becomes less similar to people. Adults, on the other hand, project the same properties more uniformly across the category *animal* with some effect of subcategory distinctions such as vertebrates/invertebrates . While this developmental change normally occurs hand in hand with detectable conceptual changes, it, in and of itself, reflects none, and need not involve one. Simple enrichment and elaboration of the existing category animal could suffice.

For our purposes performance on this task is measured by computing the difference of the proportion of bodily properties attributed to animals minus twice the proportion of bodily properties attributed to non-living inanimates. Scores are reported as percentages.

• *Projection of a Novel Property taught on People* This is another inductive inference task based on those used by Carey (1985). The purpose of this task is to confirm that the patterns generated in the attribution tasks are true inferences reflecting the role of the concept *animal* in a subject's conceptual system as opposed to the recitation of a list of memorized facts. The use of a novel property insures this.

Our version of the task uses the novel property 'omentum'. The subjects are told they are going to learn a new word, told the word, asked to say it themselves, and asked if they have ever heard it before. If they claim to have heard it, a different word is selected. The subject is shown a schematic sketch of a round, red thing and told, 'See this, this is an omentum. Lots of things have omentums in them. One of the things in the world that has omentums is people. People have omentums right about here inside (experimenter points to the midsection of a picture of a person)'. The subject is then asked which of the seven objects used in the attribution task have omentums, with one additional probe on cows (cows are added in order to insure comparability with the novel property task taught on dogs described under the conceptual change battery. The inclusion of cow is necessary to replace the object, dog, for projection.) The taught-on animal, in this case people, is probed last. In order to interpret a given subject's results the subject must get the taught-on item correct.

Carey showed that when a novel property is taught as a property of people, it generates developmental patterns of projection which closely resemble those generated by properties such as 'has a heart.' This is because it taps the same animal/non-animal distinction as the properties in the attribution task. Performance on this task is measured by computing a single difference score in the way described above for the Attribution task.

• *Category Fluency* This task is a variation on the standard fluency task as reported in Bellugi, et al. (1992). In the standard task the subject is given a category and told to name as many members of the category as quickly as possible in one minute. In our version, we put no speed requirement or time limit on the subjects because we know that people with WS have word retrieval problems and we are not so much interested in their fluency per se as we are in the size and organization of their categories. Therefore, all subjects, both WS and controls are allowed to continue listing items until they spontaneously give up. Subjects were given three categories in all; animals, food, and furniture. For the purposes of this study we are only interested in their responses to the animal category. The acquisition of category members seems to involve no conceptual change, given that normal children as young as two or three have been shown to have the same category of animal as adults (Mandler, 19xx; Massey and Gelman, 1988), with one exception which will be discussed below, that of people as animals. Subjects' scores were calculated by counting the total number of items a subject produced and then subtracting any items which were repetitions of previous items, as well as those which were non-category members (intrusions).

Conceptual Change Tasks

The normal literature on the acquisition of biological knowledge contains several well-documented examples of conceptual changes in which the intuitive adult concepts are incommensurable with the child's. Among these are 1) the differentiation of the concepts of *dead, inanimate,* and *unreal* as diagnosed by standard animism tasks (Carey, 1985; Laurendeau and Pinard, 1962; Piaget, 1929). 2) the reanalysis of *death* from a completely behavioral interpretation to include a biological interpretation as assessed by death interviews (Koocher, 1974, Nagy , 1953; Carey ,1985); 3) the shift in the concept *person* from prototypical animal to one-among-many (Carey, 1985); 4) the coalescence of the concepts of animal and plant into a single concept of *living thing*; and 5) the shift in the core features of the concept *species kind* away from physical characteristics toward origins of the animal (Keil, 1989). The successful achievement of each of these conceptual changes can be diagnosed by existing tasks in the literature. Each task detects normal adult knowledge which is incommensurable with the child state and cannot be reached without conceptual reorganizations of the child state.

• *Animism* Childhood animism is a robust phenomenon documented by Piaget (1929) and replicated by scores of people since, up to and including Carey (1985). It refers to the young child's propensity to claim that objects like the sun, the moon, the wind, fire, bicycles, etc., are alive.

Carey (1985) reinterpreted this phenomena in terms of the concept mapped onto the young child's word 'alive'. In Carey's view, the young child overattributes life due to an undifferentiated concept of *living/animate/existing*. It takes the child well into middle childhood to distinguish between these alternative conceptions of the word *alive*. Until this reorganization has been worked out, the child continues to call tables alive because you can see them, bicycles alive because they move, and the sun alive because it moves by itself.

Our task is taken from the standardized task developed by Laurendeau and Pinard (1962) . First, the child is asked if they know what it means for something to be alive and then they are given the opportunity to name examples both of objects which are and are not alive. Finally, the child is presented with a succession of twenty pictures, depicting objects from the categories of animals, plants, inanimate natural kinds, and artifacts. For each object the child is asked to judge if the object is alive and then asked to justify their answers.

Performance on our task was measured as a function of both the distribution of yes/no judgements and the nature of explanations given. Seven levels of performance were defined based on the work by both Laurendeau and Pinard (1962) and Carey (1985). The levels were as follows; *Level 0* - Random judgements; *Level 1* - Yes to all animals with at least one animistic yes. Explanations of activity, utility, or existence; *Level 2* - Yes to all animals with at least one animistic yes. Explanations include at least one explicit reference to movement (object specific movements were considered activities and assigned to level 1); *Level 3* - Yes to all animals with at least one animistic yes. Explanations include at least one explicit reference to autonomous movement; *Level 4* - Yes to all animals with at least one animistic yes. Explanations include at least one reference to non-object-specific biological process such as breathing, eating, growing, etc. (i.e. for objects where that process is not a canonical activitiy such as flowers growing.); *Level 5* - Yes to all animals, no animistic yeses, but failure to attribute life to at least one plant; *Level 6* - Yes to all animals and plants, no animistic yeses.

• *Death* The death interview taps a related misconception. Work in the literature (Koocher, 1974; Nagy, 1953) shows that young children interpret death in behavioral terms. The young child is likely to describe a dead person as going away so that they can not be seen again or as falling into a permanent sleep and never waking up. Adult understanding entails the construction of a body-as-biological-machine concept around which the concept of death is then reanalyzed. While never entirely forgoing the earlier conceptions, the adult understanding becomes centered around the biological notion of the breakdown of the bodily machine.

Our death interview includes a series of questions designed to engage the subject in thinking about death in order to assess their understanding. The interview includes the following questions. 'Do you know what it means to die?', 'Can you name some things that do die?', 'What happens to a person when it dies?' (followup on any mention of burial or heaven), 'Do you know what might cause an X to die?'.

Subjects' responses are coded for the degree to which they interpret death biologically or behaviorally. Subjects were scored on three preliminary categories, *physicalist-body* interpretations (the adult interpretation), *behavioralist-body* interpretations, and *behavioralist-departure* interpretations. Subjects received credit for a given category if they expressed any evidence of that interpretation. The three interpretations were characterized in the following way. *Physicalist-body* interpretations consisted of statements which described death in terms of the failure of body parts ("because their heart stops and they stop breathing", "because everything inside stops working", or even, "because it hurts their insides") or by describing what happens to the body after death in terms of the material decay of the body ("their body rots and the skin falls off" or "they turn to dust"). *Behavioralist-body* interpretations consisted of descriptions which referred to the cessation of bodily behaviors, as opposed to the functions of body parts. Examples of these included references to "falling asleep and never waking up", " stopping moving" "stopping talking or thinking", or "stopping doing anything" where the whole person is the doer rather than the body or the organ. *Behavioralist-departure* interpretations were the third category. These responses included statements which referred only to the fact that the person who dies "goes away", "isn't here anymore", "never comes back", or "can't be seen anymore", without regard to the person's body.

Two types of statements were ambiguous and were coded relative to the context in which they appeared. If the subject said that the dead person went to heaven without a clear indication that they meant the soul, it was coded as behavioralist-departure (e.g. Expt: What happens to a person when they die? Subject: They go to heaven. Expt: What happens to their body? Subject: I don't know. Expt: Does their whole body go to heaven? Subject: Yeah.) Similarly a subject might say that the dead person is buried without any elaboration of what happens to them after burial. Mentions of burial in the absence of any other information was coded as neither behavioral nor physicalist.

Subjects' responses were coded independently for each interpretation. Subjects received one point in a category if that category's interpretation was ever reflected in their responses. Otherwise they received no points. Overall scores were computed by subtracting the two behavioralist scores from the physicalist score. By coding these three types of interpretations independently it was possible to find subjects who had both behavioralist and physicalist interpretations. This reflects the fact that even in normal development the shift from entirely behavioral to largely physicalist interpretations is neither simple nor swift.

• *Golgi: The Projection of a Novel Property taught on Dog* This is another inductive inference tasked based on those used by Carey (1985). It is used to diagnose the shift from the concept of people as the prototypical animal to a concept of people as one animal among many. It is exactly like the projection from people task used in the enrichment set with one exception. In this case, the novel property (now 'golgi') is taught as a property of dogs instead of people. The subjects are asked whether each of the eight objects from the attribution task, plus cows, have a 'golgi'. The taught-on-animal, in this case dog, was probed last. Again, the subject must get the taught on item, correct, in order to be able to interpret their other responses.

Carey found that when a novel property is taught on dogs (or some other non-human animal) rather than people, the resulting projection patterns reveal a previously undetected conceptual reorganization going on between the ages of four and ten years. Normal ten-year-olds will project a novel property with as equal likelihood from dogs to people as they will from people to dogs. In both cases the likelihood of the 'projected to' object is less than the 'projected from' object, but it is a symmetrical function. This result suggests that the ten-year-old considers the people and dogs to have equal status within the category 'animal' for the purpose of bodily inferences. The four-year-old however is very different. A four-year-old will project a novel property like omentum from people to dogs with about the same likelihood as 'heart', say roughly 75%. But given a novel property (golgi) taught on dogs, the four-year-old will not project it back to people at all, or very little, certainly not to the same extent as they do from people to dogs. Carey argues that this asymmetry reflects the special status that people play in the four-year-old's conceptual system. To the four-year-old, people are not one animal among many. This conception, common to ten-year-olds and adults is the result of a reanalysis of the role of people in the category of animal/biological thing.

Performance on this task is measured solely by the subjects answer to the question "Do people have golgis inside them?" A score of one means the subject said yes and a zero means they said no.

• *Attribution to Tree* This task is used to detect whether or not the subject has constructed the ontological category of *living thing*. The task is embedded in the larger attribution task of the Enrichment Battery. In addition to asking subjects whether or not animals and non-living inanimates have each of four bodily properties, we ask them whether or not trees have these properties (breathes, has a heart, hears, has babies). Normal subjects show a developmental trend of increasing likelihood to attribute these properties to trees. Four-year-olds rarely attribute them to trees, treating trees like any other non-animal object. Adults, on the other hand, attribute them significantly more often to trees than to other inanimates, reflecting their acknowledgement that trees share certain properties with animals, specifically universal biological properties like breathing and have babies. This pattern is not seen until subjects have constructed the superordinate category (and ontological concept) of *living thing* which includes both animals and plants.

Performance is measured by the number of bodily properties that the subject attributes to trees. The score can range from zero to four.

• *Species Transformations* This is a task developed by DeVries (1969) and Keil (1989) in which it is possible to assess the core aspects of a subject's species concept. The basic form of the task involves a story, accompanied by pictures (or in De Vries' case real animals), in which an animal starts out being and looking like a member of one species (e.g. a raccoon), undergoes a transformation of some sort, and ends up looking like a member of another species (e.g. skunk). The child's task is to say what kind of animal the animal *is* after undergoing the transformation. In all cases the endstate looks like a real member of the new species.

The likelihood that a subject will claim that the racoon has actually become a skunk depends on the subject's age and the mechanism of the transformation, e.g. a costume, temporary surface paint, permanent surgery, or an internal injection or pill (Keil, 1989). The youngest children, three-year-olds, will accept any transformation including a costume change (DeVries, 1969). Kindergarteners will accept plastic surgery but not a costume change, second graders will accept injections but not plastic surgery or costumes (Keil, 1989) and so on. (Notice that children well past the appearance/reality watershed will accept the appearance as representative of reality under certain conditions.) Keil concludes that this developmental pattern reflects the change in an ever-increasing sophistication of biological understanding of bodies. We agree and go further to argue that the increasingly sophisticated biological knowledge that children are demonstrating is the reversal of their core and peripheral notions of what constitutes an animal's kind. For the young child, physical characteristics are central to an animal's identity. Origins of the animal and the origin of its properties are peripheral if acknowledged at all. For the adult, origins of the animal and origins of its properties become central to the kind identity of the animal and the actual type or appearance of the properties becomes peripheral. Normal adult performance thus entails this reorganization of the core and peripheral features of the concept of *species identity.*

Our tasks are taken directly from Keil's materials and includes two stories of costume transformations and two stories of surgery transformations. The costume stories include a goat being costumed to look like a sheep and a zebra being costumed to look like a horse. The surgery stories include a raccoon turned into a skunk lookalike and a tiger turned into a lion lookalike. For each trial, after the subject has heard each story, they are asked "Now, when the father/shepherd/doctor is done and the animal looks just like this, what kind of animal is it?" The subject's first response is recorded and then the subect's response is challenged (for both correct and incorrect answers). If the subject vacillates or changes their mind that is also recorded.

The method of scoring is also taken directly from Keil in order to take advantage of his normal data. Subjects receive a score of 1 to 3 for each story. They receive a 1 if they change the animal's identity on their first response and stick to that response throughout the challenges. They receive a 2 if they show any hesitation or confusion about the answer. This can be reflected by "I don't know" responses or by changing their answers at any point during the trial. Subjects received a score of 3 if they resisted changing the animal's species kind throughout the trial. Subjects' scores were averaged over the four trials.

Results

WS versus Matched Controls (MC)

Every WS subject was assigned their own matched control for the entire study. Every comparison reported reflects those matches. Subjects received an overall score for each task. Average scores for the WS group and their matched control group are shown by the bar graphs in Figures 1-8. Both parametric (paired t-tests) and non-parametric (Wilcoxon signed-rank) analyses were performed on the scores in each task.

Recall our prediction. WS subjects will show the same levels of performance as their matched controls on tasks which require no conceptual changes and will show significantly worse levels of performance on tasks which do require conceptual changes. Statistically that prediction translates into no significant difference on any of the Enrichment Tasks and significant differences on all of the Conceptual Change tasks. Because of the specific direction of our prediction with respect to the Conceptual Change tasks we use one-tailed levels of significance throughout. This in turn, results in a tougher criteria with respect to our prediction on the Enrichment tasks (We predict the two groups will be the same, but a one-tailed test lowers the threshold of detecting a significant difference, thereby working against us.) Results for both statistical tests are described below along with selected examples of subjects' responses.

Enrichment Tasks - WS vs. MC

• *Attribution (Figure 1)* The difference scores of the WS subjects averaged 74% and the scores of their matched controls averaged 87%, $t(9) = -1.58$, $p<.10$. Seven of the ten pairs had higher control scores, two had higher WS scores, and one tied, Wilcoxon $z = -1.54$, n.s. (N=10). Both tests failed to reach significance. These results show that both groups of subjects were constrained by the animal/non-animal distinction and were equally knowledgable about the particular bodily properties probed.

• *Projection from People (Figure 2)* The difference scores of the WS subjects averaged 60% and of the matched controls, 71%, $t(9) = -0.79$, n.s. Five of the ten pairs had higher control scores and four had higher WS scores. One paired tied. This resulted in a Wilcoxon $z = -0.96$, n.s. (N=10). Again, both tests failed to reach significance, showing that both groups use the category of animal *productively* and equally broadly when making novel inferences about likely body parts.

• *Category Fluency (Figure 3)* Two of the WS subjects failed to complete this task, leaving eight matched pairs for direct comparison. On this task the WS subjects produced an average of 14.6 animals and the matched controls produced 15.9, $t(7)= -0.88$, $p = .20$. Of the eight pairs, three reflected higher control scores and four reflected higher WS scores, while one pair tied, Wilcoxon $z = -0.68$, n.s. (N=8). Performance on this task was equivalent by both measures. The two groups of subjects produced lists of comparable length and content. The following are a typical examples from two matched pair.

WS(S9): bird, cat, fish, dog, mouse, seafish, possum, skunk, raccoon, chicken, pigs, turkeys, flamingos, birds (I already said that), elephants, tigers, lions, whales.

MC(S9): elephant, tiger, lion, seal, walrus, ape, gorilla, dog, cat, rabbit, squirrel, chipmunk, skunk, porcupine, weasal.

WS(S3): scorpions, zebras, lambs, snakes, horses, sheep, lambs, turkey, rooster, cat, dog, fish, cat, camel.

MC(S3): deer, horse, cow, dog, people, bird, whale, giraffe, dolphin, horse, elk, mountain lion, rhinosauras.

Conceptual Change Tasks - WS vs. MC

• *Animism (Figure 4)* The average stage level achieved by the WS subjects was 2.3, reflecting a majority of subjects in stages well within the animistic realm of an undifferentiated concept of animate, existing, and alive. The matched controls achieved an average stage level of 5.1, reflecting near-ceiling performance by the control group. The comparison of these means resulted in a significant difference, $t(9) = -4.58$, $p < .001$. Of the ten pairs, nine control subjects scored higher than their WS match and one scored the same, Wilcoxon $z = -2.69$, $p < .01$ ($N=10$). These results show that with respect to the achievement of the adult concept of alive, the WS subjects are significantly behind their matched normal controls. WS subjects have not reinterpreted the concept alive to refer to the biological concept of life, while the majority of the controls have. Examples of typical responses are shown for a matched pair.

Expt: Is a car alive?

WS(5): **The car is definitely alive cause it helps you get places you need to go to.**

Expt: Is a cat alive?

WS(5): **Yes they are.**

Expt: How do you know?

WS(5): **They wouldn't purr for me if they're not alive.**

Expt: Is a car alive?

MC(5): **No.**

Expt: How do you know?

MC(5): **Well, they're mechanical.**

Expt: Is a cat alive?

MC(5): **Yes.**

Expt: How do you know?

MC(5): **Because it has a heart and it breathes and it smells and it hears.**

• *Death (Figure 5)* One WS subject failed to complete this task, leaving nine pairs for comparison. The WS group attained an average score on this task of -0.67, reflecting the fact that they all had largely behavioralists interpretations of death, although some made physicalist responses as well. The matched control group had an average score of 0.4, reflecting an almost unanimous reliance on physicalist interpretations, although some of them also made behavioralist-body statements. Unlike the WS subjects, none of the controls gave departure type responses. The comparison of these means resulted in a significant difference, $t(8) = -4.26$, $p < .002$. Of the nine pairs, seven reflected higher control scores and two contained ties, Wilcoxon $z = -2.43$, $p < .02$ (N=9). These results show that the WS subjects are significantly behind their matched controls in the reinterpretation of death as a biological phenomena. The following are examples of responses.

Expt: What happens to a person when they die?

WS(3): They faint.

Expt: And then?

WS(3): They sleep.

Expt: And then?

WS(3): They close their eyes.

Expt: What happens to a person when they die?

MC(3): They turn white and they turn into a skeleton. They lose all their skin. They can't think anymore. They can't feel anymore. They can't do any of the things they could do when they were alive.

• *Golgi (Figure 6)* The WS group projected the novel property taught on dogs to people an average of 20% of the time (two of the ten subjects) while the matched control group projected it 80% of the time (eight of the ten subjects), $t(9) = -3.67$, $p < .01$. Of the ten pairs, six times the control scored better than the WS and four times they tied, Wilcoxon $z = -2.45$, $p < .02$ (N=10). This result demonstrates the failure of the WS subjects to have analyzed people as one animal among many.

• *Attribution to Tree (Figure 7)* Of the four possible items to attribute to trees, breathes, has babies, has a heart, hears, only the first two are routinely attributed to trees by adults (unpublished data). WS subjects attributed the biological properties probed to trees an average of 0.9 times out of a possible 4 chances. The matched controls attributed an average of 1.5 of the properties to trees. This comparison resulted in a significant difference, $t(9) = -2.25$, $p < .05$. Of the ten pairs of subjects, six had higher control scores, one had a higher WS score, and three tied, Wilcoxon $z = -1.90$, $p < .06$ (N=10). By parametric measures the WS were significantly behind the normal controls in their construction of the superordinate category of living thing, upon which this task rests. Non-parametric measures of the difference reached marginal significance.

• *Species Transformations (Figure 8)* One WS subject and three control subjects failed to complete either of the species transformation tasks. Two of the control subjects were replaced for this task by additional controls also matched on the PPVT-R, bringing the final number of matched pairs to nine. Overall, WS subjects judged that the animal's species identity was changed with a score of 1.57 Matched controls, on the other hand leaned the other direction, towards judging that the animal's identity remained the same, with an average score of 2.22, $t(8) = -2.29$, $p < .05$. Of the nine pairs, six had higher control scores, one had a higher WS score, and two were tied, Wilcoxon $z = -1.87$, $p < .10$. Again, by parametric measures, the WS subjects were well behind the matched controls. They have not reanalyzed their concept of kind membership such that origins of the animal and its properties are core properties and surface characteristics are peripheral. Several of the younger controls were still in the process of this reinterpretation themselves, as reflected by lower scores from the younger controls than the older controls and the only marginal significance of the non-parametric test. Examples of typical responses are shown.

Plastic surgery: Raccoon transformed into skunk

Expt: So after the operation, when the animal looked like this what kind of animal was it?

WS(10): A skunk, because they put that smelly stuff in it.

Expt: So even though it started out looking like this, what do you think it is?

WS(10): A skunk.

Expt: Its parents were raccoons and its babies are raccoons. Now what do you think it is?

WS(10): A skunk.

Expt: So after the operation, when the animal looked like this what kind of animal was it?

MC(10): A raccoon.

Expt: So even though it looks like a skunk, you think it's a raccoon?

MC(10): Yes.

Costume: Zebra transformed into horse

Expt: So when the costume is all in place and the animal looks like this, what kind of animal is it?

WS(10): A horse, of course it's a horse.

Expt: Why's that?

WS(10): Cause it has a tail....and it looks more a horse than a zebra.

Expt: So even though it started out looking like this, what do you think it is?

WS(10): I think it's really a horse.

Expt: So when the costume is all in place and the animal looks like this, what kind of animal is it?

MC(10): Zebra.

Expt: So even though it looks like a horse, what do you think it is?

MC(10): Really a zebra.

The pattern of results here confirm our first prediction exactly. The two groups exhibit equivalent performance on all three tasks tapping factual knowledge as represented by the Enrichment tasks and compared by both parametric and non-parametric methods. Conversely, the WS subjects were significantly worse on all five tasks which diagnose the reorganization of biological knowledge as represented by the Conceptual Change tasks. Of the ten parametric and non-parametric comparisons, eight reflected significantly worse performance by the WS subjects. Two of the non-parametric tests just missed significance. These results provide the first piece of evidence needed to argue that WS results in a selective impairment in the abilities required for successful conceptual change. The second piece of the argument is provided by the comparison with younger normally developing controls.

WS versus Younger Controls (YC)

Recall our discussion before on the purpose of a younger control group. In order to show that any dissociation found within WS subjects is not merely the reflection of a normal progression in development, we must also compare our WS subjects to a group of slightly younger controls who are nonetheless above floor on these tasks. Statistically, the same dissociation at an earlier point in normal development would result in no significant difference on any of the Enrichment Tasks and no significant differences on all of the Conceptual Change tasks, between the WS subjects and the younger group, when tested with a two-tailed, unpaired t-test.

However, even equivalent performance on the Enrichment tasks and mixed performances on the Conceptual Change tasks, would be ambiguous. Given the fact that this control group was not selected to respresent the *average* six-year-old, any success on some Conceptual Change tasks, not accompanied by worse performance on some Enrichment task, could be interpreted as the result of two subgroups, one of which shows the dissociation (the average children) and the other which is more like the older matched controls (the above average children) and does not. Therefore it is especially important to our hypothesis that the younger controls as a group perform worse than (i.e. developmentally behind) the WS subjects on at least one of the Enrichment tasks.

Data was collected on only a subset of the tasks here and is represented in Figures 9-15. In one case (species transformation) the comparable data shown is taken from the literature (Keil, 1989).

Enrichment Tasks - WS vs. YC

• *Attribution (Figure 9)* The scores of the younger controls averaged 94%. This differed significantly from the WS group average of 73%, $t(19) = -2.30$, $p < 0.05$. Notice that the group average is higher than either of the other groups, reflecting the fact that there is a normal developmental trend to overgeneralize within the category animal before the subcategory of vertebrates/ invertebrates is learned (Carey, 1985). This higher average therefore actually reflects a developmentally earlier performance. This is a case of the younger controls performing 'worse' than the WS subjects.

• *Projection (Figure 10)* The average score of the younger controls was exactly the same as the WS subjects at 60%, $t(17) = .006$, n.s. Both groups of subjects were able to use the category of animals productively to infer the possession of a novel property.

Conceptual Change Tasks - WS vs. YC

• *Animism (Figure 11)* The average stage level achieved by the younger controls was 4.8, reflecting a majority of subjects in stages well on the way to a differentiated concept of animate, existing, and alive. This compared to the animistic 2.3 score of the WS subjects, $t(19) = -3.64$, $p < 0.01$. The younger controls were significantly ahead of the WS subjects in their analysis of the concept *alive*.

• *Death (Figure 12)* The younger controls attained an average score on this task of 0.20, reflecting all three interpretations of death, but less so than the WS subjects. Far fewer of the younger controls gave departure type responses. The comparison to the WS subjects, who also gave all three interpretations, but especially departure responses, with an average score of -0.67, resulted in $t(18) = -2.35$, $p < .05$. The younger controls were significantly ahead of the WS subjects in their interpretation of death as a physicalist-body phenomenon.

• *Golgi (Figure 13)* The younger group projected the novel property taught on dogs to people an average of 30% of the time while the WS group projected it 20% of the time. This comparison was non-significant, $t(18) = -.49$, n.s. Both groups have failed to conceive of people as one animal among many.

• *Attribution to Tree (Figure 14)* The younger controls attributed the biological properties probed to trees an average of 0.73 times out of a possible 4 chances. This compared to the 0.90 attributions of the WS subjects, $t(19) = 0.57$, n.s. Neither group has completed the coelescence of trees and animals into the superordinate category of living things.

• *Species Transformations (Figure 15)* Data from Keil (1989) is shown. Keil's six-year-olds on these same tasks scored an average of 2.22 points, which is exactly the average attained by our matched controls. Although we cannot perform the statistics on this average, it seems a fair assumption that like our matched group, Keil's six-year-old's scores would be significantly higher than our WS subject's scores.

These results confirm our second prediction and provide evidence for the second half of our argument. The younger controls demonstrated levels of conceptual achievement relative to the WS subjects which could not be predicted by the set in which a particular task occurred. They performed behind the WS subjects on one Enrichment task and equivalently on the other. They performed ahead of the WS subjects on three of the Conceptual Change tasks and equivalently on the other two. This allows us to conclude that the dissociation seen in WS does not simply reflect a normal conceptual system delayed beyond the mental age reflected in their vocabulary achievements.

DISCUSSION

These results reflect a remarkable pattern in the conceptual systems of people with WS which we believe is never seen at any level of normal development. We believe nonetheless, that it is understandable in terms of current accounts of development which claim that concepts at all ages are embedded in explanatory structures and that these explanatory structures are constructed by the individual learner. All of our WS subjects showed high levels of factual knowledge about animal properties as diagnosed by the attribution tasks. Their knowledge was organized like that seen in normal adults, reflecting the categories of animals and non-animals and supporting inferences about 'biological' properties to uncommon, atypical animals like worms, but not to non-animals like ragdolls, despite their perceptual similarity. In addition, their knowledge was definitely generative, as seen by projection patterns of a novel property. That is, they could infer that an object they had never encountered before but which was described as an internal part of people, was probably also an internal part of birds and worms, but not of ragdolls or computers. Finally, they could produce as many examplars of the animal category as subjects of the same mental age. All of these measures suggest remarkably well-organized and inferentially productive conceptual knowledge at least as sophisticated as their verbal mental age would predict.

However, on all of our tasks involving conceptual changes, our subjects performed more closely to four-year-olds than to adults. They failed to demonstrate any reliable evidence of the conceptual changes normally acquired by the age of ten. They were widely animistic often overattributing life to inanimate, non-biological objects such as mountains, the sun, and cars. They did not reliably include plants in their category of living things and their justifications for their judgments resembled those of four year olds. They did not understand death to be the breakdown of a physical machine but instead gave behavioral interpretations reminiscent of four-year-olds. They claimed that the dead person went away or fell asleep and one subject who claimed that the person went to heaven, on further probing about the fate of the body, claimed the body went to heaven too, except for the feet and legs, which other people could still see. They failed to project novel body properties to people when they were taught on dogs, rejecting the notion that people are one animal among many, despite simultaneously accepting them as the prototypical animal on the projection from people task. And finally, they believed an animal's species identity could be manipulated by plastic surgery or even a costume. All of these are conceptual achievements within the domain of an intuitive biology that the normally developing child accomplishes between the ages of four and ten. In many cases our WS subjects' responses were comparable to or behind that of normal four-year-olds.

These results allow us to conclude several things. The basic result shows that people with Williams syndrome, though generally impaired as reflected by PPVT mental ages well below their chronological ages, are significantly more impaired in the ability to acquire categorical knowledge which requires conceptual changes than in the ability to acquire categorical knowledge which does not. This conclusion is warranted by the comparisons of people with WS to two different types of control groups. Neither comparison suggested that the WS performance patterns are found in normal development. When compared to normal children matched on vocabulary achievement, the WS subjects were equally competent on all three tasks in the Enrichment battery but significantly worse on all six tasks in the Conceptual Change battery. Furthermore, as shown by their comparison with younger normal controls, it does not appear that the WS performance can be explained as a conceptual delay on top of their already delayed vocabulary achievement. Unlike the WS subjects, the performance of younger controls on individual tasks was not predicted by which of the batteries the task belonged to. WS subjects and younger controls performed equivalently on one of the Enrichment tasks and three of the Conceptual Change tasks, and differently on another of the Enrichment tasks and the other three Conceptual Change tasks. This allows us to conclude that the dissociation seen in WS does not simply reflect a normal conceptual system delayed beyond the mental age reflected in their vocabulary achievements. Rather it reflects a conceptual system developing along a different path entirely, one which can not rely upon the conceptual revolutions provided by ordinary conceptual change.

CONCLUSIONS

What are the implications of this work for theories of conceptual knowledge acquisition and representation? These results are preliminary results. What we can say at this point is that people with Williams syndrome are unable to achieve the conceptual changes involved in normal development, while simultaneously accumulating substantial amounts of productive categorical knowledge. Both sides of the dissociation require further study in order to understand what is preserved and what is impaired in WS. What this study accomplishes is the establishment of a neuropsychological phenomenon in WS which will allow researchers one more way to isolate and study the components of conceptual development

Given this dissociation, several questions arise. With respect to the impairment which precludes the construction of intuitive theories, one would like to know whether it lies in aspects of explanatory reasoning per se, such as an understanding of causality; in more general reasoning abilities, such as analogy and general logic; or even more generally in some sort of processing limitation which constrains the complexity of the computations possible. A way of thinking of this issue with respect to theory-building is whether people with WS are unable to build explanatory theories at all or just to change them in the face of imcommensurabilites. A thorough examination of these abilities in people with WS should provide some insight into the computational abilities necessary for successful conceptual change.

Furthermore, the possibility that people with WS have more difficulty achieving the intuitive adult knowledge in some domains than in others (e.g. complete failure in biology versus a possible success in theory of mind) offers an avenue for examining the extent to which different conceptual domains rely on constructive theory-building. There is the possibility that conceptual development is qualitatively different in domains built upon innate foundations, such as is suggested for theory of mind or intuitive mechanics (Leslie, 1992) despite their similarity to intuitive biology as explanatory structures. Close comparative analysis of the developmental course of these domains within people with WS would allow this possibility to be addressed.

Another implication of this research is the extent to which this dissociation may be seen in other forms of mental retardation. Given the extent of preserved language skills in WS it is tempting to suggest that this dissociation is related to that ability and therefore unique to WS. Recall again that the dissociation rests on two facts, that WS subjects fail to make conceptual changes *and* that they succeed in building categorical representations. Their failure to make conceptual changes is certainly due to some reasoning impairment probably shared by mental retardation in general, and independent of their language skills . But their *success* might be explanable in terms of their preserved language skills, a cognitive feature not shared by all forms of mental retardation. The question with respect to mental retardation then becomes one of whether or not the preserved categorical knowledge is seen in other forms of retardation without preserved language, such as Down syndrome or non-specific retardation. If this dissociation is found across the spectrum of mental retardation it will offer a new perspective on the debate among researchers on whether retardation is the result of delayed development or deviant development.

Finally, the presence of preserved categorical knowledge in WS raises another distinct issue with respect to research into normal concept representation. If it turns out that the success in WS is isolatable to a categorization achievement in the absence of conceptual change, questions arise about the precise structure, organization, and inferential role of those categorical representations. There is the possibility that learning mechanisms such as association are perfectly intact in WS. If so, one question then becomes, do WS subjects show prototype and typicality effects such as the ones described and studied in the literature on normal adult representations. This possibility offers the unique opportunity to isolate the both of the respective contributions of prototype-related and theory-related mechanisms to normal conceptual acquisition and representation.

BIBLIOGRAPHY

Bellugi, U., Birhle, A., Neville, H., Jernigan, T., Doherty, S., (1993) Language, cognition, and brain organization in a neurodevelopmental disorder, In M.Gunnar and C. Nelson (Eds.), *Developmental Behavioral Neuroscience*, Minnesota Symposiaum. Hillsdale, NJ: Erlbaum Press.

Bihrle, A., Bellugi, U., Delis, D., and Marks, S., (1989). Seeing either the forest or the trees: Dissociation in visuospatial processing, *Brain and Cognition*, 11, 37-49.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Carey, S. (1988). Conceptual differences between children and adults. *Mind and Language,* 3, 167-181.

Carey, S. (1991). Knowledge acquisition: Enrichment or conceptual change? In S. Carey and R. Gelman (Eds.) *The Epigenisis of Mind: Essays on Biology and Cognition*, Hillsdale, NJ: Erlbaum.

Carey, S., Johnson, S.C., and Levine, K. (1993). Conceptual structure of adults/adolescents with williams syndrome. *Poster at SRCD conference,* New Orleans.

Carey, S. and Spelke, E. (in press). Domain specific knowledge and conceptual change. In L.A. Hirschfeld and S.A. Gelman (Eds.), *Domain Specificity in Cognition and Culture.* New York: Cambridge University Press.

DeVries, R. (1969). *Constancy of genetic identity in the years three to six.* Monograpshs of the Society for Research in Child Development, 34, Chicago: University of Chicago Press.

Dilts, C.V., Morris, C.A., and Leonard, C.O. (1990). Hypothesis for development of behavioral phenotype in williams syndrome. *American Journal of Medical Genetics Supplement,* 6, 126-131.

Dunn, L.M. and Dunn, L.M. (1981). *Peabody Picture Vocabulary Test - Revised,* Circle Pines, MN: American Guidance Service.

Gelman, S.A. and Wellman, H.M. (1991). Insides and essences: early understandings of the nonobvious. *Cognition,* 38, 213-244.

Gopnik, A. and Wellman, H.M. (1993). The theory theory. In L. Hirsch and S. Gelman (Eds.) *Domain specificty in cognition and culture.* New York: Cambridge University Press.

Inagaki, K. and Hatano, G. (1987). Young children's spontaneous personification as analogy. *Child Development*, 58, 1013-1020.

Jernigan, T. and Bellugi, U. (1990). Anomalous brain morphology on magnetic resonance images in williams syndrome and down syndrome, *Arch Neurol,* 47.

Johnson, S.C., Solomon, G.E.A., and Carey, S. (1994). Why dogs have puppies and cats have kittens: Young children's understanding of species kind and the inheritance of properties. this volume.

Jones, K. and Smith, D. (1975). The Williams elfin facies syndrome: A new perspective, *Journal of Pediatrics*, 86, p.718-723.

Karmiloff-Smith, A. (1988). The child is a theoretician, not an inductivist. *Mind and Language*, 3, 183-193.

Karmiloff-Smith, A. and Grant, J. (1993). Linguistic and cognitive development in williams syndrome: a window on the normal mind. *Poster at SRCD conference*, New Orleans.

Keil, F.C. (1989). *Concepts, kinds, and cognitive development.* Cambridge, MA: Bradford Books.

Keil, F.C. (1992). The origins of an autonomous biology. In M.R. Gunnar and & M. Maratsos (Ed). *Modularity and constraints in language and cognition: the Minnesota symposia on child psychology,* 25, Hillsdale, NJ: Erlbaum.

Kitcher, P. (1988). The child as parent of the scientist. *Mind and Language,* 3, 217-227.

Koocher, G.P. (1974). Talking with children about death. *American Journal of Orthopsychiatria,* 44, 404-410.

Kuhn, T.S. (1962). *The structure of scientific revolution.* Chicago: University of Chicago Press.

Kuhn, T.S. (1982). Commensurability, comparability, and communicability. *PSA1982*, vol.2.

Laurendeau, M. and Pinard, A. (1962). *Causal thinking in the child: a genetic and experimental approach.* New York: International Universities Press.

Leslie, A.M. (1992). ToMM, ToBy, and Agency: core architecture and domain specificity. In L.A. Hirschfeld and S.A. Gelman (Eds.), *Domain Specificity in Cognition and Culture.* New York: Cambridge University Press.

Levine, K. (1993). Cognitive profiles in Williams syndrome. unpublished manuscript. Boston's Childrens' Hospital.

Mandler, xx

Massey, C. and Gelman, R. (1988). Preschooler's ability to decide whether a photographed unfamiliar object can move itself. *Developmental Psychology*, 24, 307-317.

Mervis, C.B. and Bertrand, J. (1993). Early language and cognitive development: implications of research with children who have williams syndrome or down syndrome. *Poster at SRCD conference,* New Orleans.

Morris, ? (1994)

Murphy, G.L. (1993). Theories and Concept Formation. In I. Mechelen, J. Hampton, R. Michalski, and P. Theuns (Eds.) *Categories and ConceptsL Theoretical Views and Inductive Data Analysis*, San Diego: Academic Press.

Nagy, M.H. (1953). Children's conceptions of some bodily functions. *Journal of Genetic Psychology,* 83, 199-216.

Nersessian, N.J. (1992). How do scientists think? Capturing the dynamics of conceptual change in science. In R.N. Giere (Ed.) *Cognitive Models of Science. Minnesota Studies in the Philosophy of Science*, 15, 344. Minneapolis: University of Minnesota Press.

Piaget, J. (1929). *The child's conception of the world.* London: Routledge and Kegan Paul.

Smith, C., Carey, S., and Wiser, M. (1985). On differentiation: a case study of the development of the concepts of size, weight, and density. *Cognition*, 21, 177-237.

Solomon, G.E.A., Johnson, S.C., Zaitchik, D., and Carey, S. (1993). Like father, like son: Young children's understanding of how and why offspring resemble their parents. submitted for review.

Spelke, E. (1991). Physical knowledge in infancy: Reflections on Piaget's theory. In S. Carey and R. Gelman (Eds.) *Epigenisis of Mind: Essays on Biology and Cognition*, Hillsdale, NJ: Erlbaum.

Spelke, E. and Carey, S. (in press). Domain-specificity and conceptual change, In L. Hirsch and S. Gelman (Eds.) *Domain specificty in cognition and culture.* New York: Cambridge University Press.

Udwin, O. and Yule, W. (1991). A cognitive and behavioral phenotype in williams syndrome. *Journal of Clinical and Experimental Neuropsychology,* 13(2), 232-244.

Vosniadu, S. and Brewer, W.F. (1992). Mental models of the earth: a study of conceptual change in childhood. *Cognitive Psychology.*

Wellman, H.M. and Gelman, S.A. (1992). Cognitive development: foundational theories of core domains. *Annual Review of Psychology*, 43, 337-375.

Williams, J.C.P., Barrett-Boyes, B.G., and Lowe, J.B. (1962). Supravalvular aortic stenosis. *Circulation,* 24, 1311-1318.

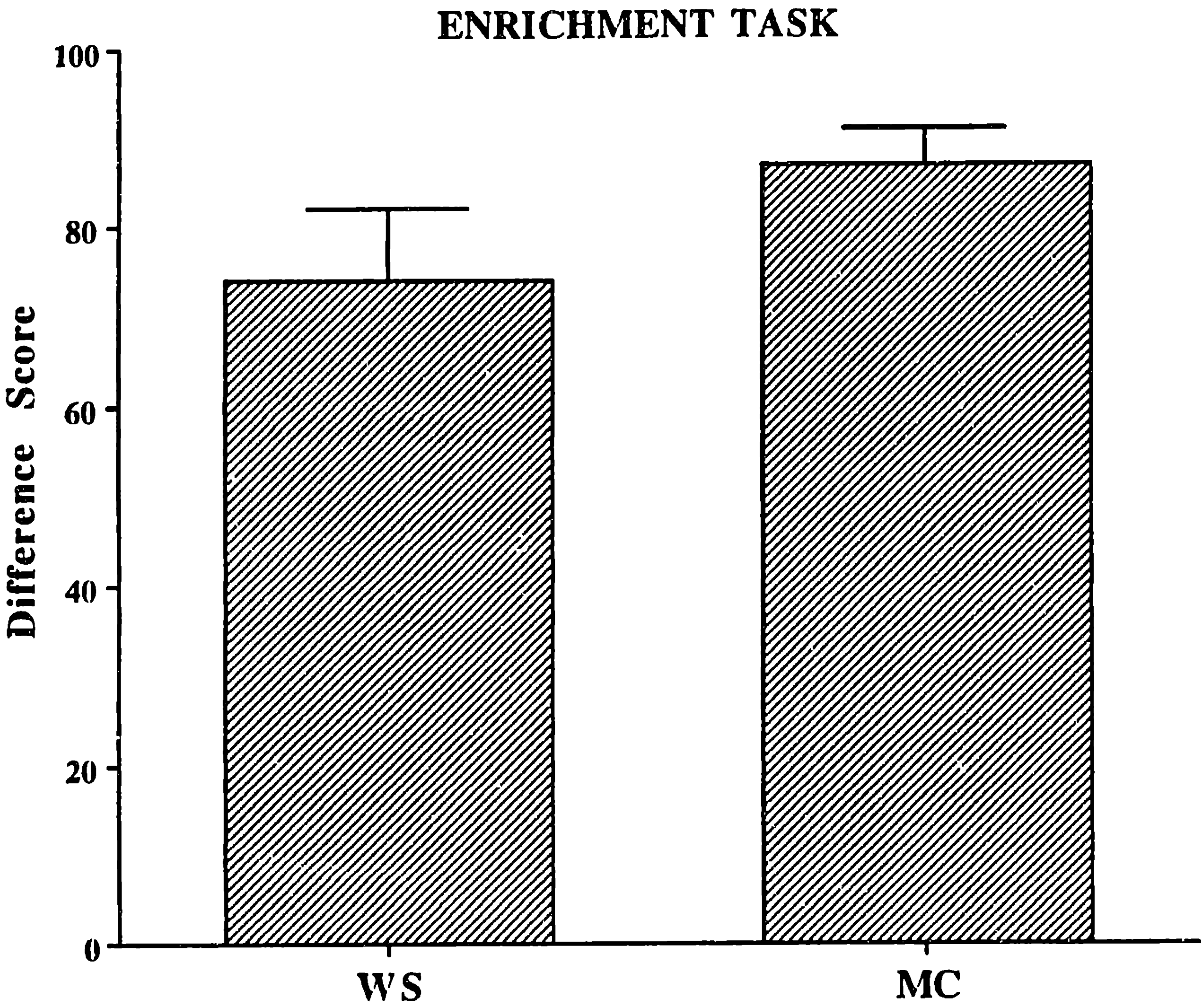

FIGURE 1. Attribution of 'Biological' Properties

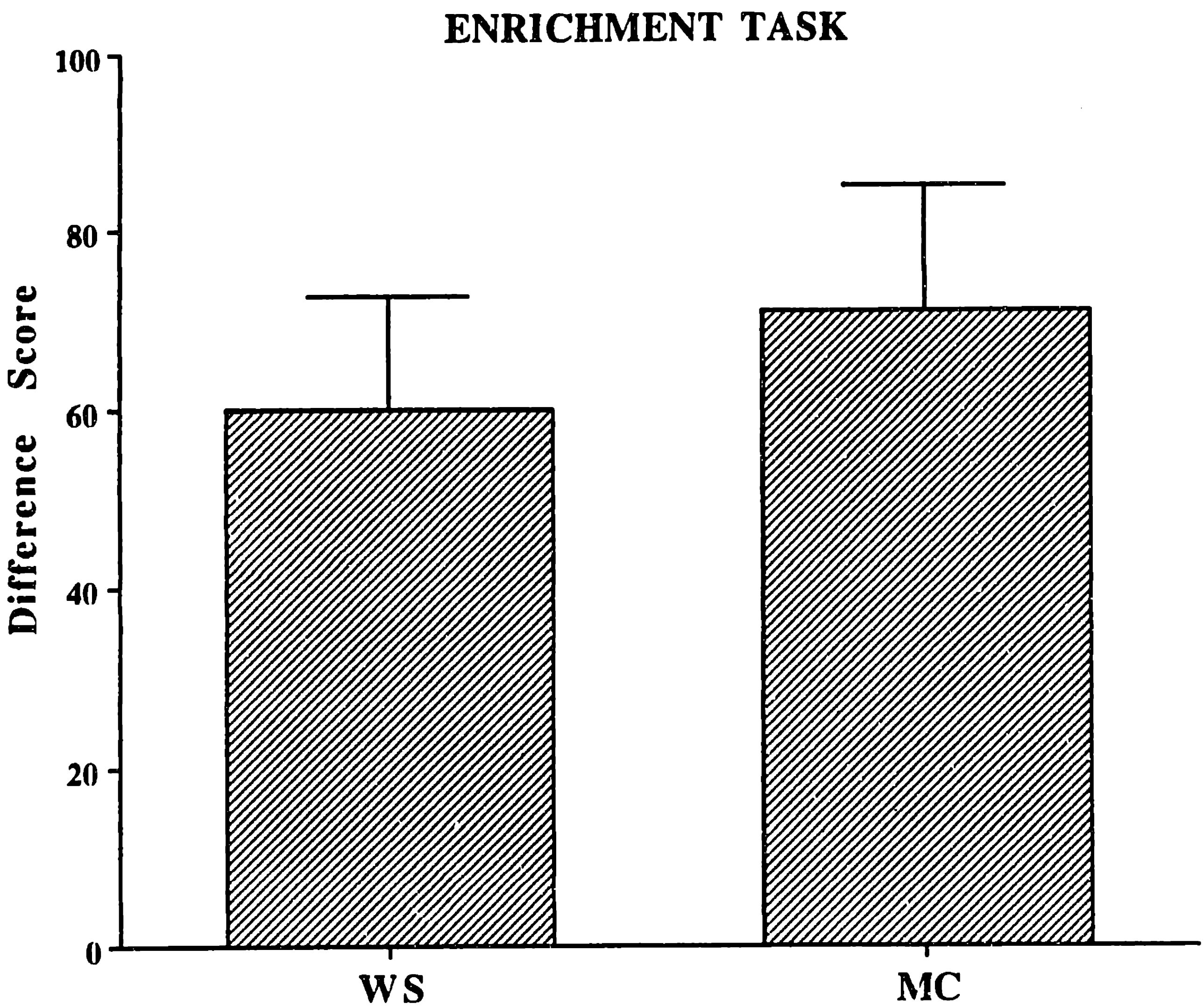

FIGURE 2. Projection of Novel Property taught on People

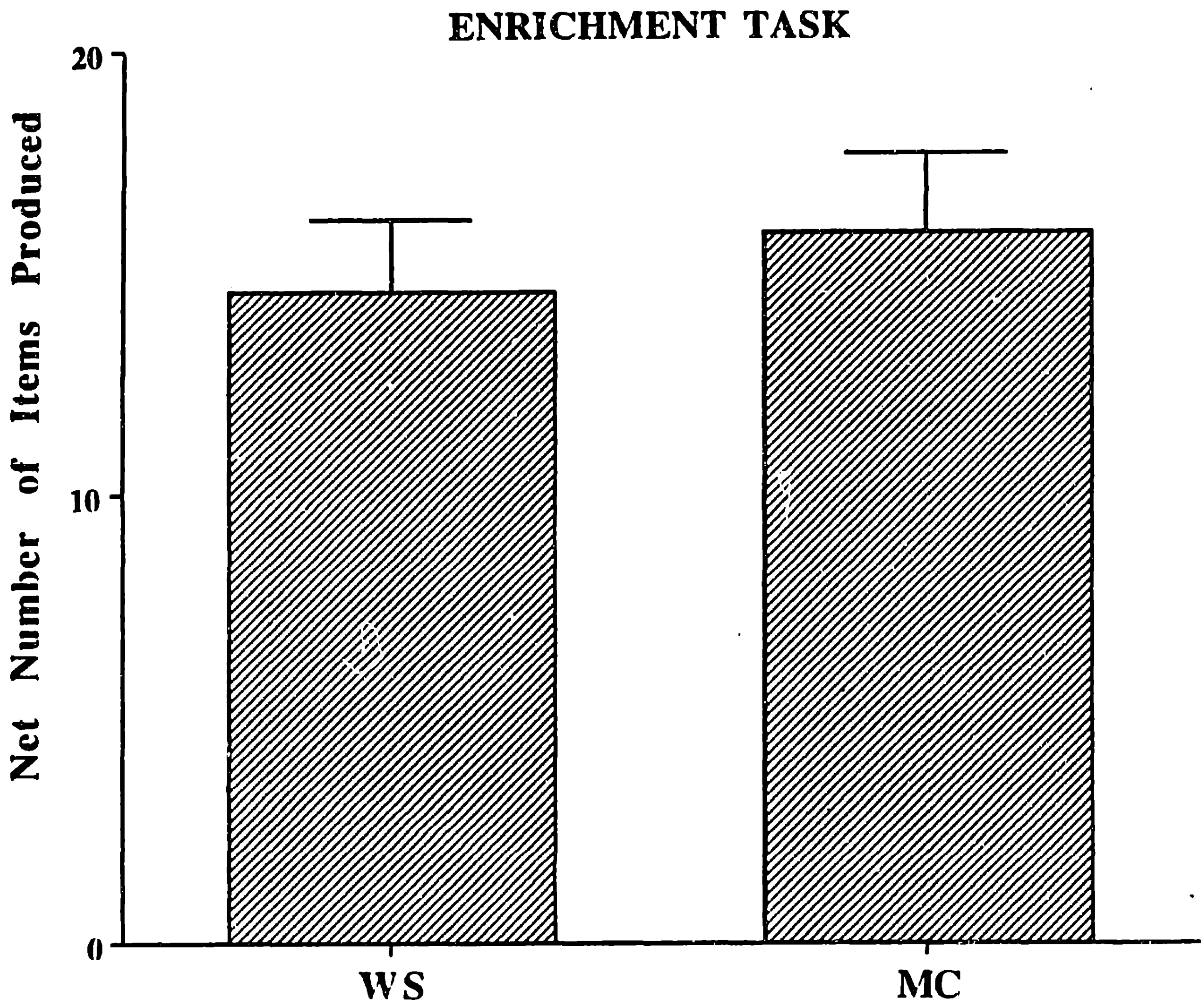

FIGURE 3. Category Fluency: Animals

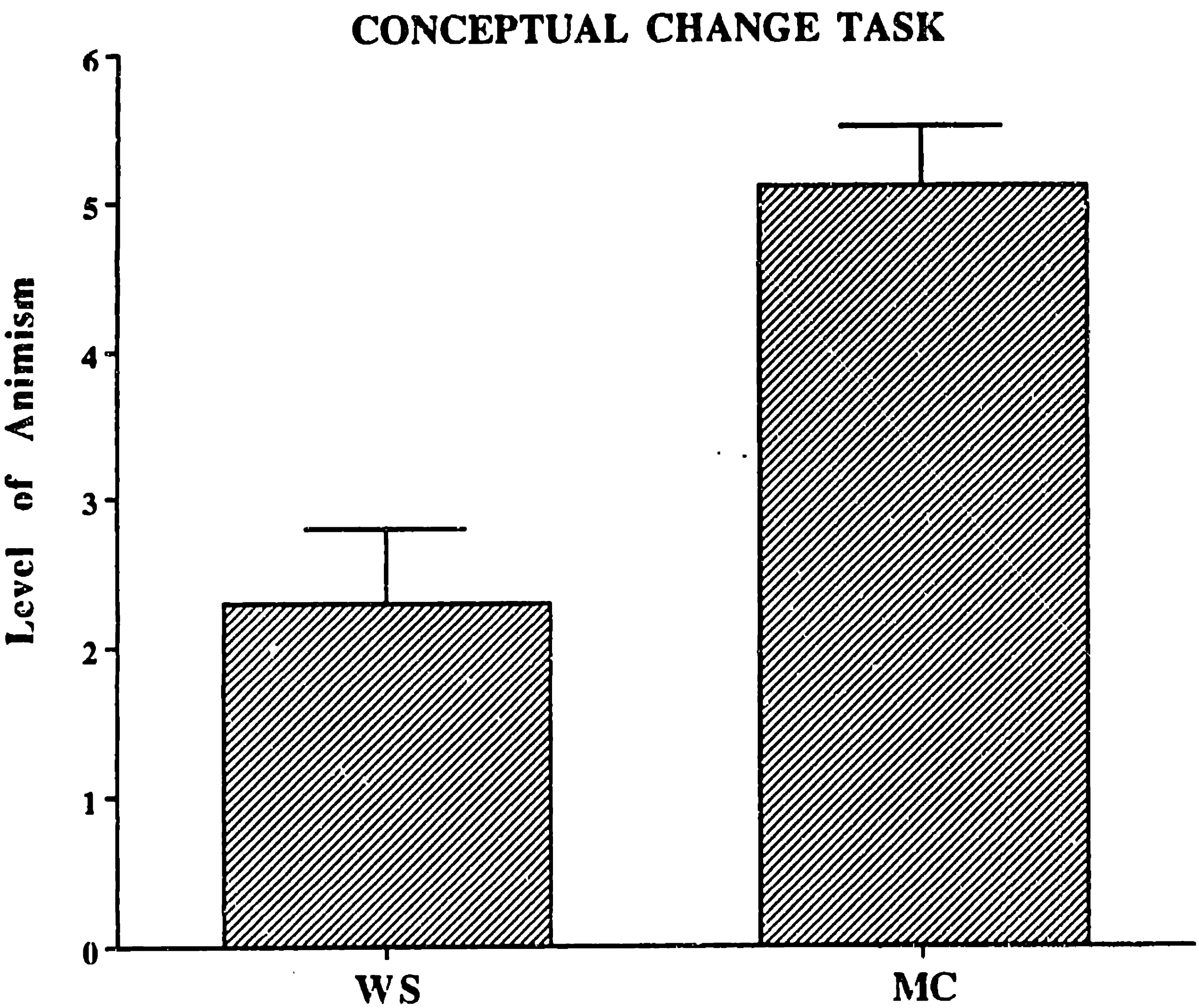

FIGURE 4. Animism Interview

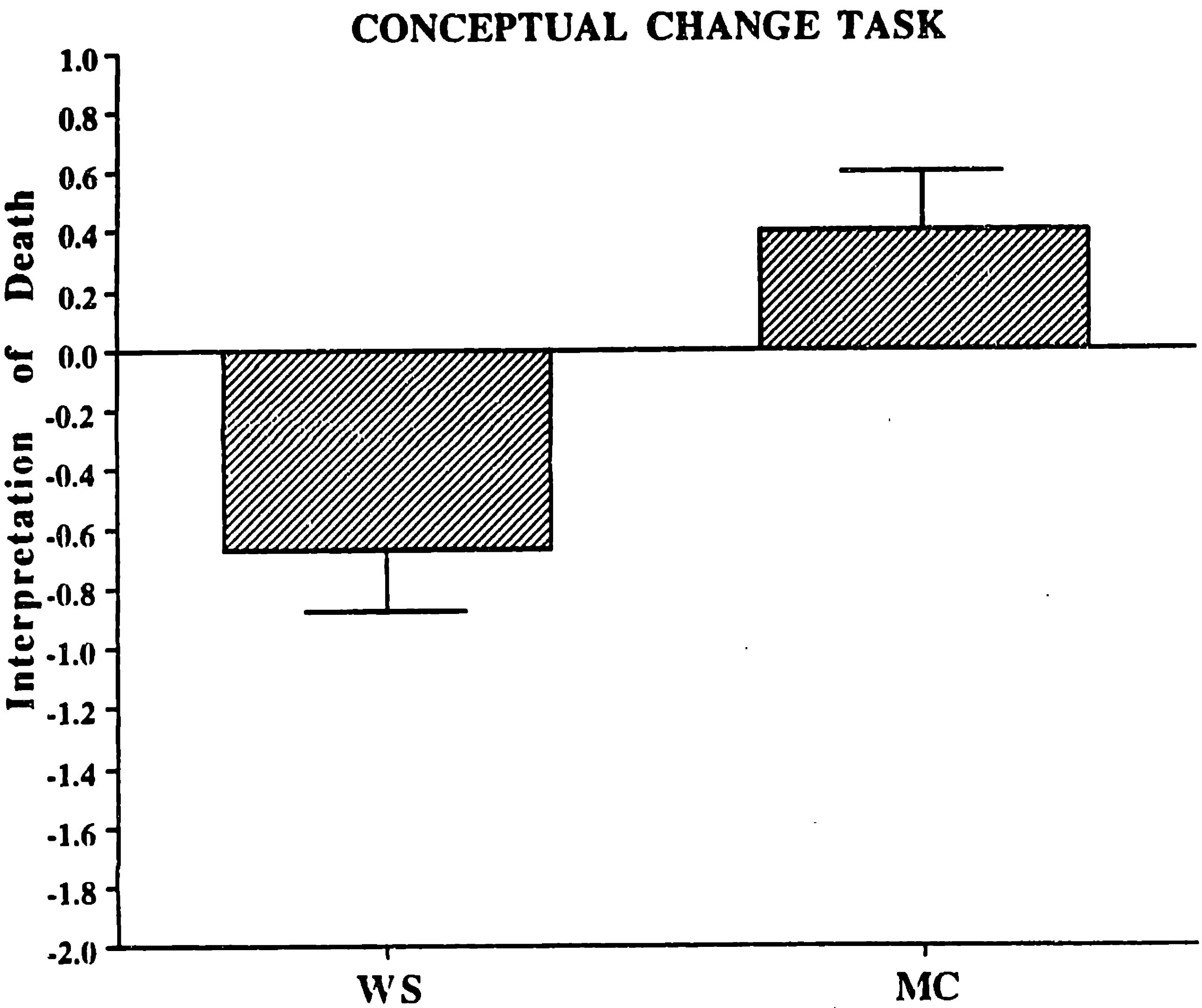

FIGURE 5. Death Interview

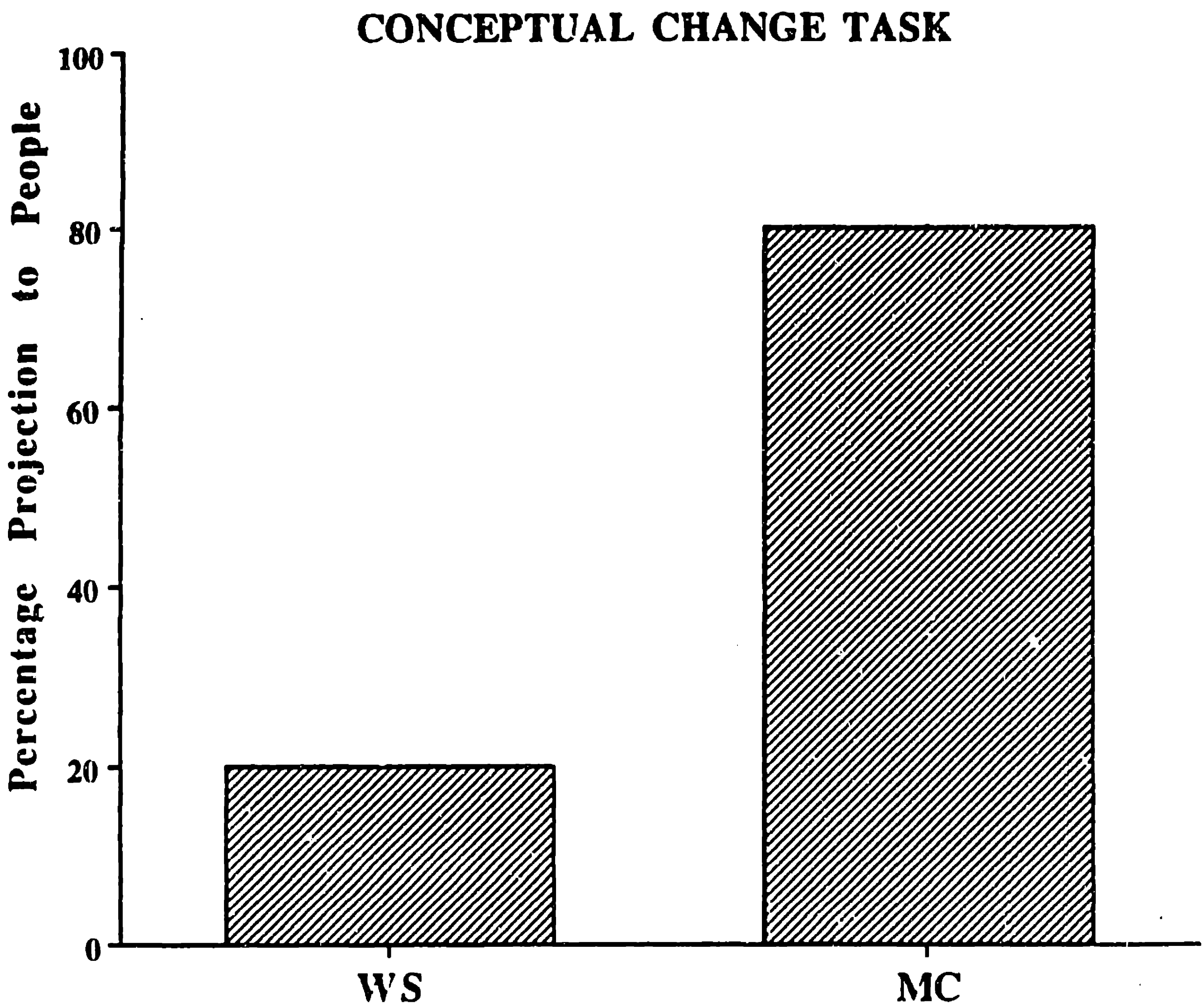

FIGURE 6. Projection of Novel Property taught on Dog

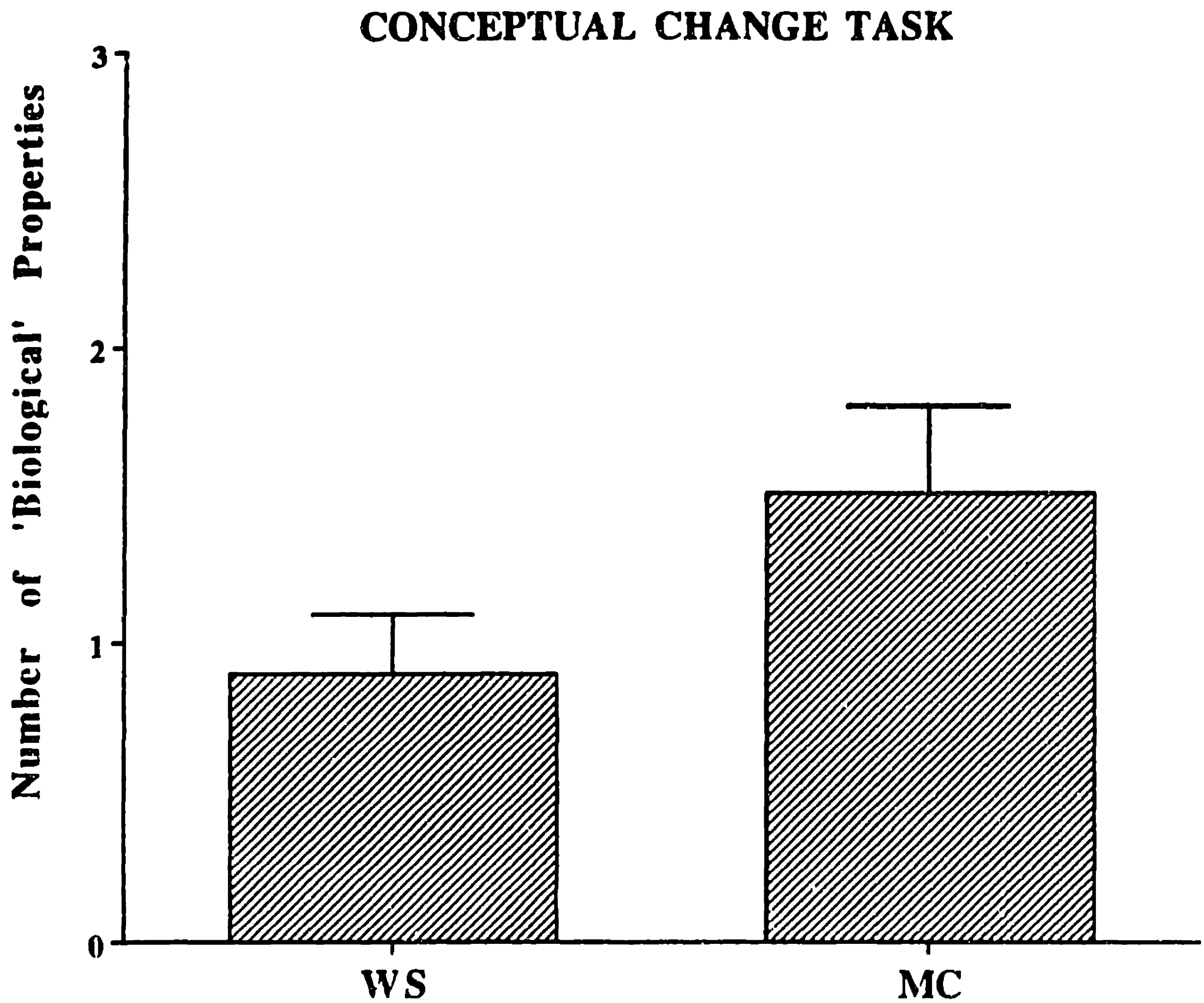

FIGURE 7. Attribution of 'Biological' Properties to Trees

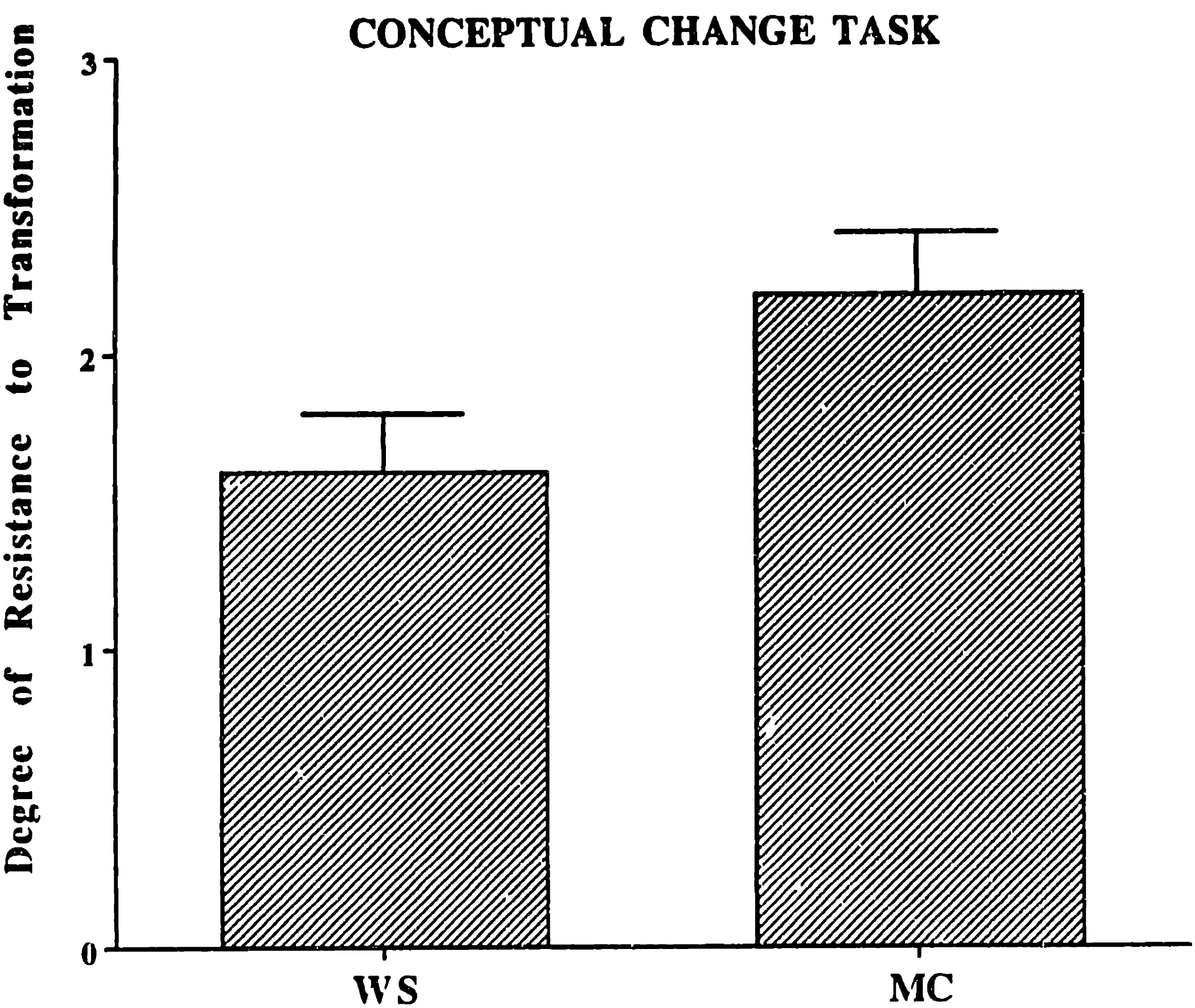

FIGURE 8. Species Transformation

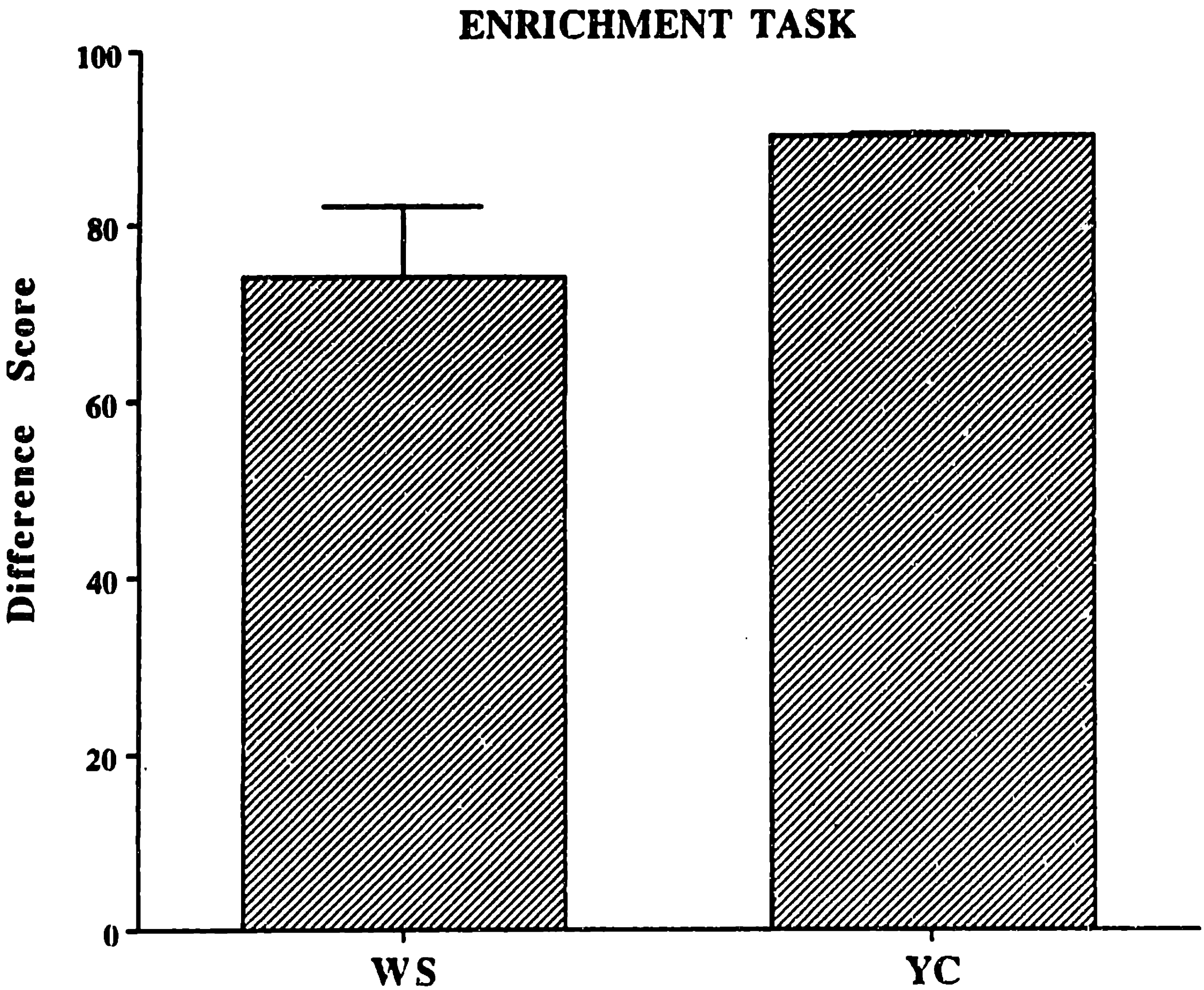

FIGURE 9. Attribution of 'Biological' Properties

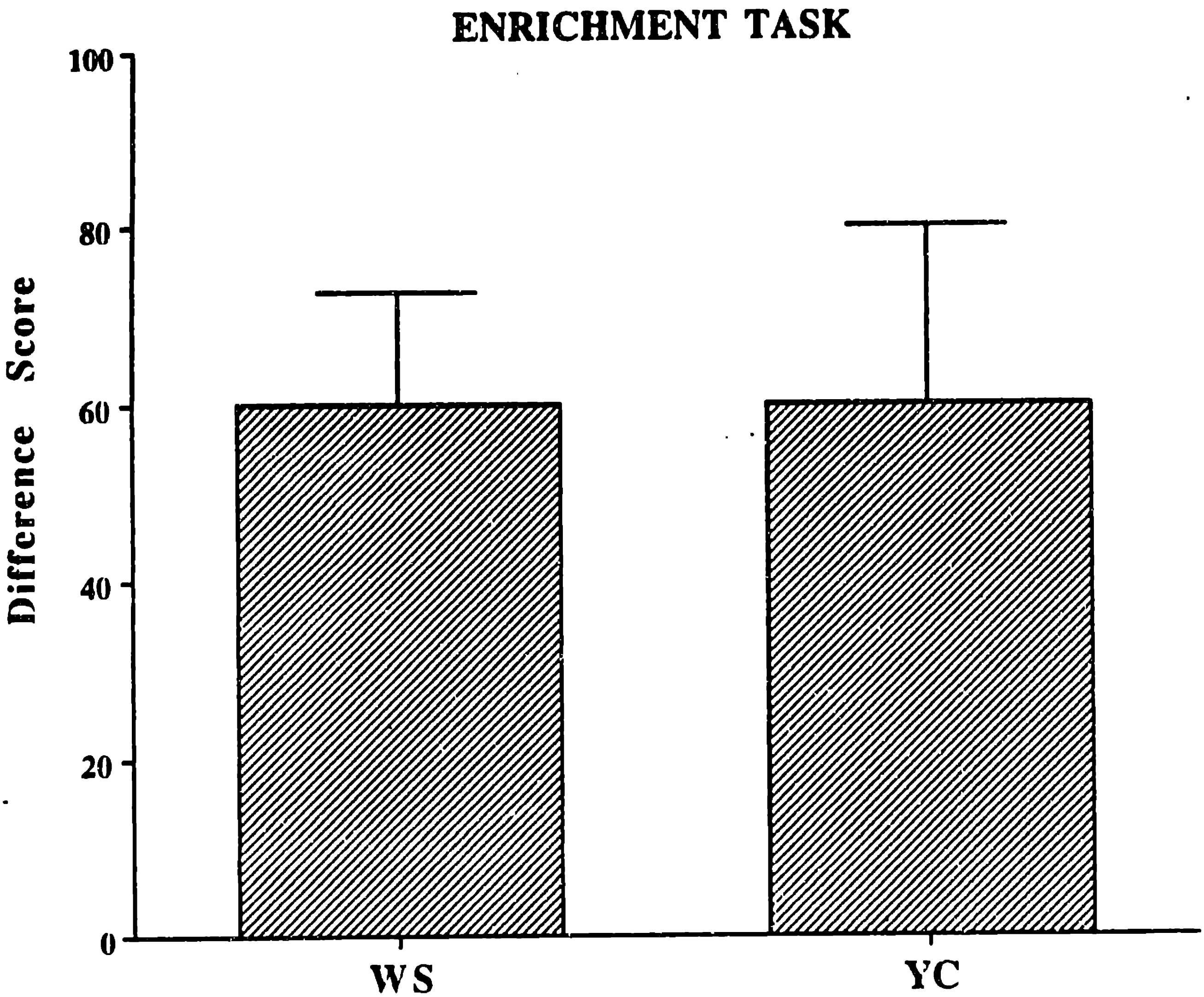

Figure 10. Projection of Novel Property taught on People

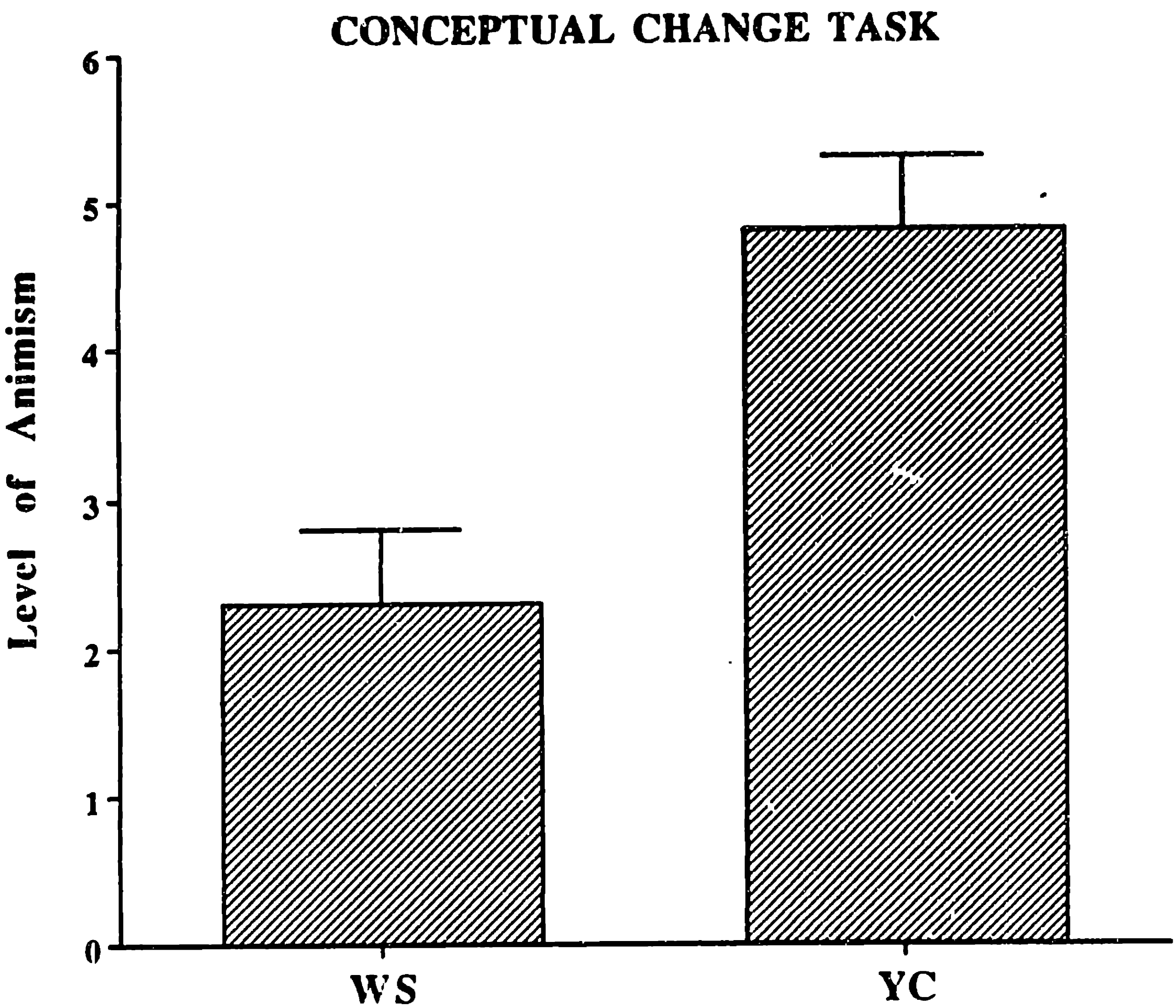

FIGURE 11. Animism Interview

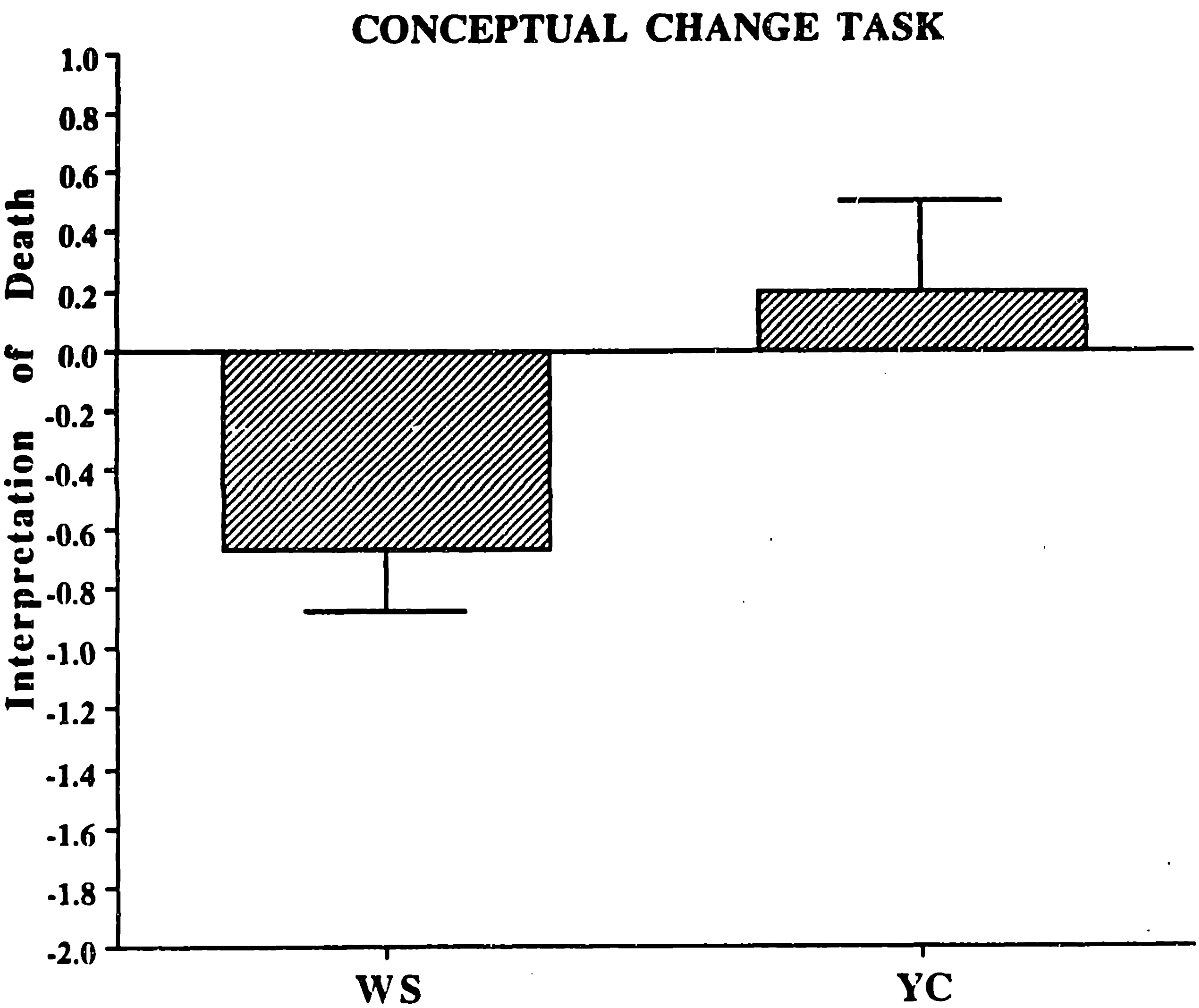

FIGURE 12. Death Interview

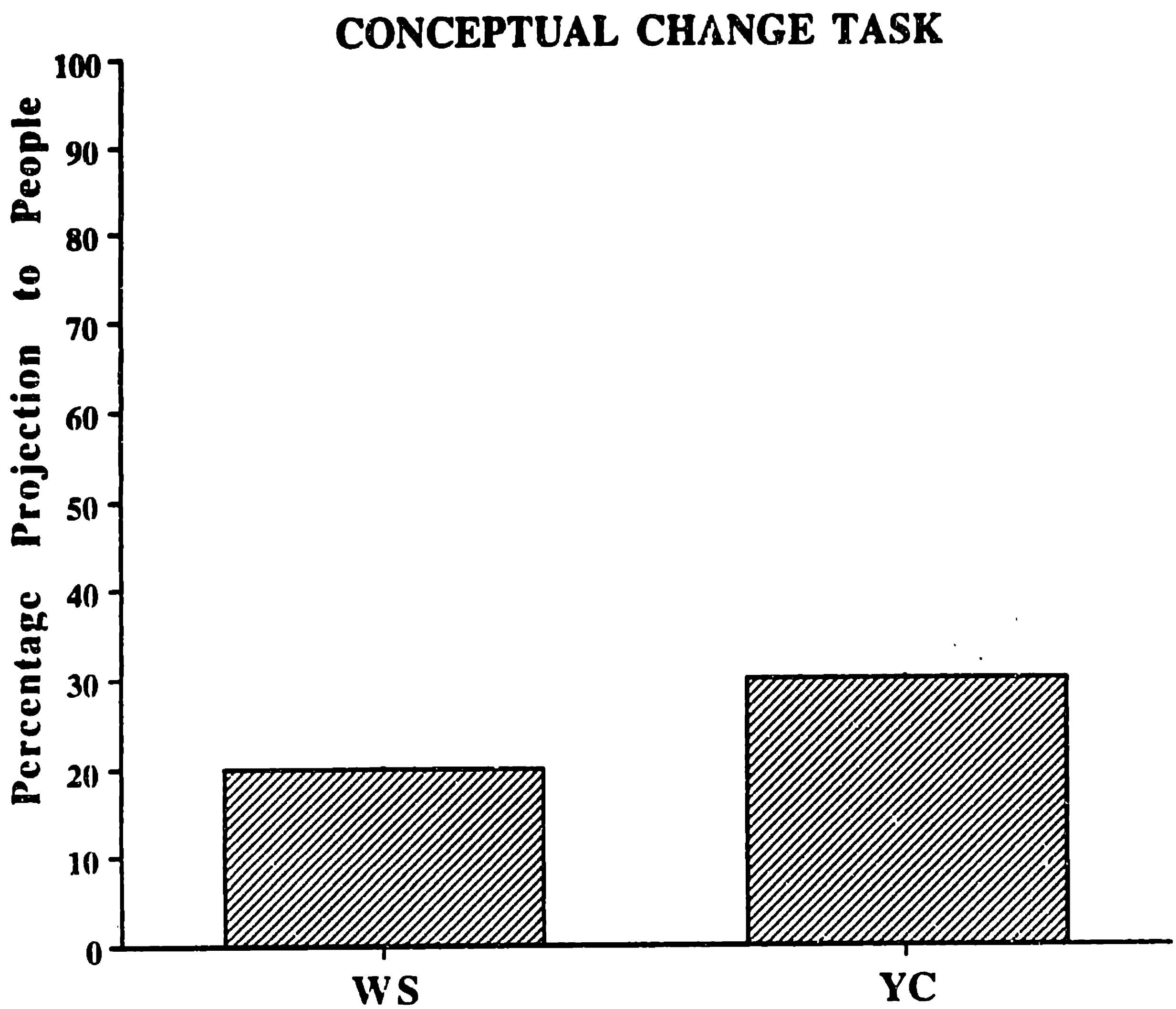

FIGURE 13. Projection of Novel Property taught on Dog

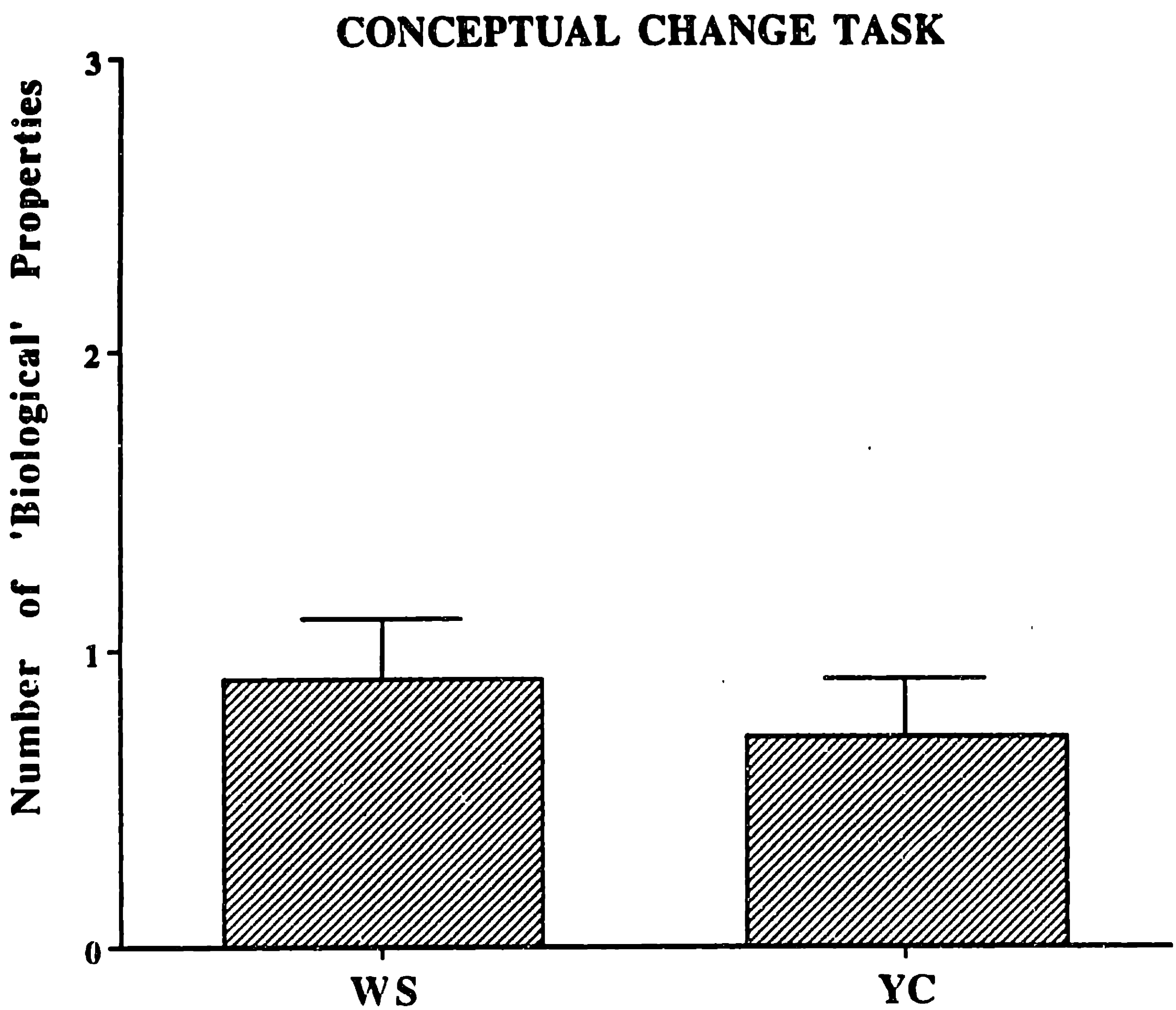

FIGURE 14. Attribution of 'Biological' Properties to Trees

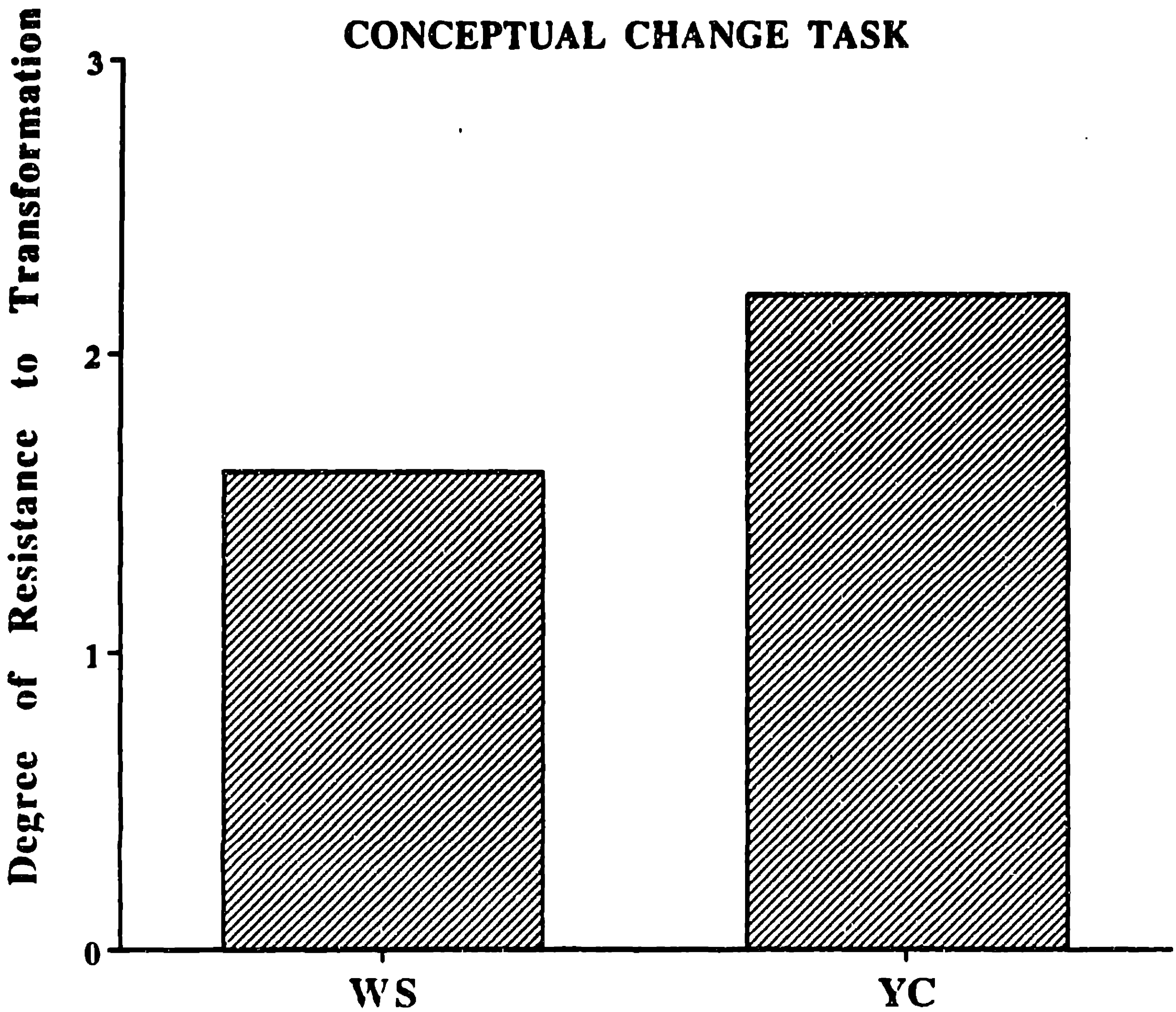

FIGURE 15. Species Transformation
YC data from Keil (1989)