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The Development of Explanations for Biological Phenomena:

Children's and Adults' Understanding of Inheritance

by

Connie A. Korpan ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY

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DEDICATION

With much love to my family for their support from start to finish.

Abstract

In the developmental literature, the most prevalent view of conceptual understanding is that, when we are faced with the task of identifying and explaining what we observe, we understand it within the context of a theoretical framework. This research concerns biological understanding of inheritance. Among other things, biological understanding entails knowing that biological processes operate outside the forces of mechanical and intentional causes. A question that has been the center of much debate is: When do children possess such understanding? Of particular interest has been when children can be said to construe biological phenomena from within a biological rather than psychological theoretical framework. One view is that before the age of approximately 7 years, children interpret biological phenomena in terms of psychological forces such as beliefs and intentions and that between 7- and 10- years of age, they undergo something akin to paradigm shift. That is, they begin to develop a theoretical framework related to biology that is autonomous from psychology and begin to interpret appropriate phenomena from within this framework. The other view is that children possess an autonomous theoretical framework related to biology at a much earlier age. This study is based on the assumption that thinking about biological phenomena is variable within individuals and within age groups and that global portrayals of conceptual development could be enriched by portrayals emphasizing variability. Of particular interest in the current study is the types of explanations individuals endorse or generate when thinking about biological inheritance.

In this study, students in Grades 2, 4, 6, and university were systematically and intensively interviewed on the topic of inheritance. They were presented with three tasks.

In the Generation Task, participants were presented with a variety of items intended to elicit explanations about how physical traits are inherited across one or two generations. In the Endorsement Task, participants were asked to render an opinion concerning seven explanations for the color of an animal, a plant, and an artifact. Finally, in the Background Knowledge Task, participants were asked questions that were designed to determine their knowledge about genes and the role they play in transmission of traits, their knowledge about the environment and how it influences the expression of traits, and their intuitive statistical knowledge regarding natural variability and homogeneity.

Compared to children, more adults had knowledge about genes and their knowledge was more complete. Participants in all four age groups had similar opinions about the environment and how it affects trait expression and they were similar in terms of their statistical intuitions. In the Endorsement Task, participants in Grades 2 and 4 endorsed more explanations for the color of biological entities than participants in Grade 6 and university. All groups were comparable in terms of the number of explanations they found appropriate for the artifact. Also, except for two young children, there was no evidence that participants interpreted biological inheritance in terms of a psychological framework. Instead, preferred mechanisms amongst all children included the idea that God can choose the color of living things. For the puppy, approximately half of all children also endorsed preformationism and genetic mechanism. For the flower, approximately half of the children in Grades 2 and 4 endorsed preformationism. Children in Grade 6 did not prefer any mechanism other than the idea that God can choose the color of flowers. Adults preferred the genetic mechanism for both living entities.

In the Generation Task, participants in all age groups generated approximately six

types of explanations, suggesting that participants have at hand a variety of explanations from which to choose. Furthermore, they tended to generate similar types of explanations. What develops is the frequency and consistency with which various explanations are generated. Adults tended to generate explanations that were congruous with biological theories of inheritance but included a clear causal mechanism in their explanations. Children's explanations were also mostly congruous with biological theories of inheritance, but frequently lacked a clear causal mechanism. Implications of evaluating biological understanding and its development from the perspective of multiple, overlapping explanations are discussed.

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The Development of Explanations for Biological Phenomena: Children's and Adults' Understanding of Inheritance

Growing recognition that cognition varies substantially in different knowledge domains and concurrent disenchantment with domain-general theories of cognition has led to an explosion of research on conceptual understanding (e.g., Hirschfeld & Gelman, 1994; Siegler, 1989; Springer, 1992; Sternberg, 1989). Claims have been advanced that the mind is heterogeneous; cognitive systems are specialized to process and represent different sorts of conceptual knowledge and not others (e.g., Pinker, 1994; Wellman & Gelman, 1998). Concepts are mental representations of particular events or entities that are grouped together on the basis of similarity. They allow us to interpret new experiences, organize them into coherent patterns, and to draw inferences in situations in which we lack direct experience (Wellman & Gelman, 1992). Conceptual understanding is now deemed so basic to perception, language, memory, and reasoning, that it is difficult to study it in isolation; it influences and is influenced by every aspect of our thinking (Siegler, 1998). Despite the flurry of research in this area, the particular nature of conceptual representation and the nature of conceptual development are not fully understood, and continue to serve as the foci for much cognitive research.

In the introduction to this dissertation, I first describe briefly how concepts have been considered to be represented mentally, concentrating primarily on biological conceptions. Next, I address the issue of the general nature of conceptual development. Finally, I discuss my research, in which I explore children's and adult's understanding of the biological implications of kinship.

The Nature of Conceptual Representation

How do people represent concepts? Three major alternative types of representations have been proposed, including: (a) classical, or defining-features, (b) probabilistic, and (c) theory based (Medin, 1989). From a very early age, people have been shown to be able to represent concepts in all three ways, although the prominence of each type of representation may change with learning and development (Siegler, 1998).

Defining Features

According to the defining-features view, people are said to represent a particular concept (e.g., uncle) if they know its necessary, or defining features (e.g., father or mother's brother, or aunt's husband), if they know its characteristic features (e.g., he loves me), and if they are able to use these features to decide whether a case is an instance of the concept. Piaget and Inhelder (1969) and Vygotsky (1934) conducted their research on children's conceptions from this perspective and came to similar conclusions about children's conceptual competence. Using categorization tasks, they concluded that preschool children do not group instances on the basis of defining features, but instead form thematically-related groups (e.g., cats are grouped with chairs instead of other animals because cats often sleep on chairs). They also fail to categorize instances along a single consistent dimension (Vygotsky, 1934). Around 6 years of age, children begin to demonstrate competence in identifying defining features, and thereby are able to form taxonomic or true concepts.

Researchers who have set about to discover children's early competencies dispute these findings because the conclusions were based on tasks that either ignored children's disinterest in the experimental tasks or neglected to consider the impact content knowledge has on children's performance (Siegler, 1998). In interesting tasks that involve familiar content, children are able to identify defining features of concepts, and use them to categorize instances taxonomically. For example, Keil and Batterman (1984) presented children in Kindergarten, Grade 2, and Grade 4 with short stories that described 17 familiar terms, such as "island," "vacation," and "lie." For each term (e.g., island), two stories were presented. Once story included characteristic but not defining features of the term (e.g., coconut trees, girls wear flowers in their hair), whereas the other included defining, but not characteristic features (e.g., water on all sides). Children were asked whether the story was a good illustration of the term (e.g., "Could that be an island?"). For some terms, children in Kindergarten relied heavily on characteristic features. Children in Grade 2 were in a transitional stage in that they relied on both characteristic and defining features. By the fourth grade, defining features predominated in children's definitions. When more familiar terms, such as "robber" were used, however, even 5 year-olds relied on defining features. The defining-features view itself has been criticized on the grounds that although some concepts have defining features, most do not. In reaction to this criticism, the probabalistic view of conceptual representation was advanced (e.g., Rosch & Mervis, 1975).

Probabalistic Representations

The central tenet of the probabalistic view is that for the majority of concepts, there are no defining features common to all instances. Instead, most concepts are represented in terms of their probabalistic relations to various features. Consequently, instances of concepts resemble each other to varying degrees and in varying ways, much in the way family members resemble one another (e.g., Rosch & Mervis, 1975). According to this view, individuals rely on cue validities and inter-feature correlations to form and represent concepts and to determine whether something is an instance of a concept.

Cue validities express the degree to which a feature cues a concept (Rosch & Mervis, 1975). A feature (e.g., flying) has a high cue validity if it is frequently associated a concept (e.g., birds) and infrequently associated with other concepts. Cue validities help explain why some instances (e.g., robin) are prototypical examples of a concept (e.g., bird) or are better examples of a concept than other instances (e.g., ostrich). Thus, learning the cue validities of various features is integral to concept formation and representation. Sensitivity to inter-feature associations is also essential because features do not cluster together in a random fashion. Things that fly, for example, tend to have wings, feathers, and a certain body shape. The ability to recognize and use these types of associations appears as early as 3 months of age, but is this ability all there is to concept formation and representation?

Some researchers (e.g., Carey, 1985; Keil, 1989; Wellman & Gelman, 1998) have become dissatisfied with purely probabalistic explanations because they cannot specify how people decide which features of unfamiliar objects and events should be encoded and which should be ignored. They have suggested that encoding is guided by naive or implicit theories of what is important.

Theory-based Representations

The perspective that naive theories guide encoding was not only the result of dissatisfaction with the probabalistic view of conceptual representation, but was also a consequence of the recent emergence of interest in children's foundational knowledge. Foundational knowledge refers to those bodies of knowledge (i.e., knowledge domains) that engender, shape, and constrain our naive theories of the world (Wellman & Gelman, 1998). In other words, these knowledge domains serve as theoretical frameworks which dictate the types of causal mechanisms that are appropriate for explaining phenomena. In the past, researchers such as Piaget examined children's knowledge but did so as an attempt to discover the domain-general structures and processes that children were using (e.g., memory, logic). Now, recognition that organized conceptual knowledge can have profound impact on all levels of cognition has led numerous researchers to try to understand the nature of children's foundational knowledge by directly examining their naive theories of various phenomena (e.g., Brewer & Samarapungavan, 1991; Carey, 1985; Rosengren, Gelman, Kalish, & McCormick, 1991; Springer, 1992, 1995; Vosniadou, 1989).

Naive theories are peoples' ordinary understanding of certain bounded bodies of information (e.g., theories of the earth, germs, inheritance of traits). They are coherent systems of knowledge that organize and structure everyday thinking (Wellman & Gelman, 1998). According to the theory-based view, most concepts are entrenched in naive theories that include explanations of relations among their parts and of their relations to other concepts; causal relations are basic within theories (Keil, 1989; Siegler, 1998). For example, children's naive theories of the earth include their understanding of the earth's shape (e.g., flat earth, elliptical earth, spherical earth), which is closely tied to their understanding of gravity. Gravity is a critical concept explaining why people on the "bottom" of a spherical earth do not fall off (Vosniadou & Brewer, 1992). Naive theories are also tied to people's associative knowledge and help specify which features of unfamiliar objects and events should be encoded and which should be ignored.

Naive theories are unified and constrained by a limited number of foundational knowledge domains. Three domains that appear to be important to human understanding, and are even argued to be central to human survival and interactions, include the domains of physics, psychology, and biology (Wellman & Gelman, 1998). Naive theories of physics are concerned with physical entities (e.g, solid objects, unbounded entities, such as water, and gases), both visible and invisible, as well as physical-mechanical dynamics (e.g., force). Naive theories of psychology are focused on our everyday understanding of mental contents (i.e., thoughts, beliefs, and hopes), states (i.e., emotions), and psychological causation (e.g., intentions causing purposeful action). Naive theories of biology are concerned with the distinction between living and nonliving things, the relation of humans to other species, and natural processes such as illness, death, and birth (Wellman & Gelman, 1998). They also entail an understanding of specific causal forces in biology, such as growth, reproduction, and inheritance. A question currently debated in the conceptual literature is at what ages are children able to make ontological distinctions amongst these three domains; that is, are these three domains autonomous in young children's minds?

Piaget claimed that preschool children are animists in that they construe various physical phenomena, such as rivers, as being alive, because they move (Piaget, 1929, 1930). He also concluded that preschool children are realists because they believe mental phenomena (e.g., ideas) are concrete and physical and that they are artificialists because they construe natural phenomena as products of human intervention (e.g., clouds come from chimneys). Of central importance to this dissertation is Piaget's claim that young children are incapable of making critical ontological distinctions (e.g., living versus non-living; whether psychological mechanisms can explain biological phenomena), a claim that is still being debated in the developmental literature (e.g., Carey, 1985 versus Gelman, Durgin, & Kaufman, 1995; Solomon, Zaitchik, & Carey, 1996 versus Springer, 1996). Because of the centrality of this issue to my dissertation, I briefly review the literature concerning this debate. My focus is on the debate regarding when children can be said to possess theories of biology that are distinct from psychology. The majority of the review is focused on children's understanding of biological inheritance, the particular topic of my dissertation.

Children's Biological Theories

In order for children to be said to possess biological understandings of natural phenomena, they must be able to make two critical types of distinctions. First, they must be able to distinguish living from non-living things. For example, they must understand that inanimate things do not possess animate properties, such as the ability to grow. Second, their naive theories of biological phenomena must be framed within a biological rather than psychological theoretical framework. That is, they must distinguish biological from psychological causal mechanisms and understand that only biological mechanisms underlie biological phenomena. The debate surrounds the questions, Do children make these distinctions, and if so, when?

Naive biological understanding–living versus non-living distinction. Gelman and Spelke (1981) suggested two criteria that young children could use to distinguish animate from inanimate objects, including capacity to move without external force, and the capacity to grow. Given the primacy of movement in infancy (Bertenthal et al., 1985), this type of distinction is expected to be the first that children honor. Similar to Piaget, Carey (1985) concluded that preschoolers are animistic in their thinking. Using a clinical interview that included questions such as "What is alive?" and "Why did you respond this way?" she found that children believed that the sun is alive because it moves. When less "demanding" tasks are used, however, children's causal explanations for animal movement have been found to differ from their explanations for movement of artifacts. For example, 3 year-old children understand that animals move on their own due to self-generated powers, but that artifacts that move do so as a result of human intervention, such as batteries (e.g, R. Gelman, 1990; S. Gelman, Durgin, & Kaufman, 1995).

A biological understanding of growth includes three types of conceptual insights, including the facts that (a) growth, and all other types of biological transformations, are not random, but are lawful and predictable, (b) biological transformations are domain-specific in that they apply to plants and animals, not artifacts, and (c) living things, but not non-living things, maintain their personal and/or species identity, even after undergoing dramatic changes in appearance (Rosengren, Gelman, Kalish, & McCormick, 1991). Rosengren et al. presented participants, from 3-and-a-half years to adulthood, pictures of a baby animal and a brand new artifact. Participants were told that they would be presented with two other pictures of the animal and two other pictures of the artifact. Their task was to pick out which picture in the animal-set would correspond to the animal after it has been around for a long time, and which picture in the artifact-set would correspond to the artifact after it has been around for a long time. In each set of pictures, one image was the same size as the original, the other image was either smaller or larger than the original. With regard to the first two insights, even 3-and-a-half year-old children understood that animals and plants get larger, not smaller as they age from infancy. Furthermore, they understood that only plants and animals undergo the distinctive process of growth, artifacts cannot and do not grow. Further evidence that young children possess these insights comes from Backscheider, Shatz, and Gelman (1993). They found that 3-year-old children understand that living things are self-healing (i.e., a form of re-growth), but that artifacts cannot heal themselves after being broken.

Concerning the third insight, Keil (1989) examined 5-year-old children's reaction to three types of dramatic transformations involving biological kinds and artifacts. They were presented with an illustrated story whereby one animal (e.g., racoon) was transformed, through surgery, to look like another animal (e.g., skunk). They were also presented with a picture of an artifact (e.g., coffee pot), which was disassembled and reassembled into another artifact (e.g., bird feeder). Finally, they were presented with a cross-ontological transformation (e.g., a toy bird changed into a real bird). At the age of 5 years, children understood that an animal could not be changed into an artifact, and vice versa. Keil (1989) additionally found that they understood that artifacts would lose their identity after undergoing a dramatic transformation, but "incorrectly" believed that living things would also lose their identity after being surgically transformed. Keil's reliance on unnatural transformations, such as surgery, has been brought into question, however (e.g., Rosengren et al., 1991; Gelman, 1993). Even adults may conclude that with enough surgery, an animal may lose its identity. Furthermore, when living things undergo dramatic but *natural* transformations (e.g., caterpillar to butterfly, tadpole to frog), children as young as five years of age do in fact realize that living things maintain their identity (e.g., Rosengren et al., 1991). This fact provides evidence that children are sensitive to whether the mechanism inducing change is natural (i.e., biological) or artificial.

In summary, preschool children have been shown to demonstrate some biological understanding in that they distinguish living things from non-living things. That is, they apply biological processes, such as self generated movement and growth, exclusively to living things. Artifacts are not credited with the ability to move on their own or to grow. Attributing biological understanding to young children also requires evidence that when they think about living things, they restrict their causal reasoning to biological mechanisms. One type of discrimination that been the focus of much research is children's ability to distinguish situations where biological, but not psychological, mechanisms apply. A question of particular interest has been: Do young children understand that psychological mechanisms do not play a role in biological functioning?

Naive Biological Understanding: Distinguishing Biological and Psychological mechanisms. Carey (1985) extensively studied children's ability to distinguish biological and psychological mechanisms and asserted that before the age of 7 years, children rely on an anthropocentric folk biology whereby humans are considered the prototypical instance of living things. Humans can be construed in several ways, including sentient beings whose actions are explained by psychological forces. By the age of 3 years, children understand these forces in that they are competent at reasoning backward from activities to beliefs or desires and can similarly predict behavior from beliefs and desires (Robinson & Mitchell, 1995). Carey suggested that preschoolers overextend this form of thinking to explain biological phenomena until between 7- and 10-years of age. In other words, she claimed that preschool children reason about biological phenomena using the wrong type of theoretical framework; their theories are framed in terms of psychological rather biological mechanisms. When children begin to learn that humans are just another instance of living things, which is around the age of 7 years, their naive theories about biological phenomena become differentiated from their intuitive psychological frameworks and become situated within a biological framework. This separation reflects a fundamental reorganization of theoretical frameworks akin to a paradigm shift.

Some evidence Carey used to support her claims includes children's response patterns on attribution tasks. When answering questions such as "Does X breathe?" "Does X have a heart?" and "What eats?" preschoolers respond by comparing X to humans. The more similar to humans X appears, the more likely they will say X has the trait. Other evidence includes asymmetrical inductions on property projection tasks. For example, when preschoolers are told humans have a novel trait (e.g., omenata), they extend this trait to other animals, but when they are told an animal has a novel trait, they do not extend this trait to humans. Thus, preschoolers consider humans as the privileged base for projection. Finally, on questions such as "Why do animals grow?", preschool children respond in terms of intentions (e.g., An animals grows because it wants to).

Coley, Medin, and James (1999) replicated Carey's methodology with children aged 6-, 8-, and 10-years of the Menominee Indian Tribe of Wisconsin. They addressed the question of whether differences in cultural views about the relationship between humans and the natural world affects how reasoning about biological phenomena develops. The cultural group they studied was of interest because the tribe views humans not as privileged beings in nature, but rather, as beings equal in status to other animals. No significant age effects were found in this study. Even 6-year-old children recognized humans as just another instance of animals and performed similarly to 10-year-old children on the attribution and property projection tasks. Furthermore, 6-year-old children did not explain biological processes, such as growth, in terms of psychological mechanisms. In other words, children younger than 7 years did not demonstrate a psychological construal of biological phenomena. These findings clearly demonstrate that the developmental changes seen in Carey's study do not reflect universal trends in children's thinking about biological phenomena. Furthermore, these findings highlight the importance of cultural influences on children's thinking.

Other researchers have also challenged Carey's claims and have used different sorts of tasks to study children construal of biological phenomena (e.g., Inagaki & Hatano, 1990; Springer, 1996). Similar to Coley et al. (1999), they have suggested that children younger than 7 years use biological rather than psychological theories to explain biological phenomena. For example, Inagaki and Hatano (1990) studied Japanese children's understanding of how the body works by presenting 4- and 5-year-old children with three different kinds of tasks: differentiation, controllability, and conflict (reported in Wellman & Gelman, 1992). Differentiation tasks were used to test whether children could distinguish among bodily and mental characteristics with respect to their modifiability (e.g., "Could a boy change his eye color if he wants to?"). They found that 4- and 5-year-old children could indeed distinguish means used to modify mental characteristics (intentions) from means used to modify bodily characteristics (e.g., physical practice). Controllability tests were used to measure whether children in this age-range believe that bodily functions can be controlled by intentions (e.g., "Can you stop your heart beating if you want to?"). Most children in their study responded "No." Finally, in the conflict task, children were asked such questions as "Who will become fatter, a girl who wants to get fat but who eats less or one who wants to get slim but who eats a lot of food?". If psychological laws dominate, then wanting to get fat should prevail. If psychological and biological laws are confused, then children should guess randomly. If biological laws are understood and if children recognize that in this task that biological laws conflict with psychological laws, children should report that the first girl will not get fat. The performance of an overwhelming majority of children conformed to the last option.

In subsequent studies, Inagaki and Hatano (1993, 1995) investigated whether pre-school Japanese children use only biological theories to explain biologically regulated phenomena or if they use other forms of explanations as well. In one study (1993), they presented 6- and 8-year-old children and adults with a variety of problems that were concerned either psychological processes (e.g., "Taro easily forgets things. He wants to get rid of this tendency. Can he do that?") or biological processes (e.g., "Taro has black eyes. He wants blue eyes like a foreigner's. Can he do that?"). Participants were also presented with three types of causal explanation: intentional (i.e., psychological), biological, and vitalistic. Vitalism includes the belief that internal organs have agency, or activity-initiating and activity-sustaining character. Furthermore, this agency is seen as the cause for various bodily processes (e.g., the stomach digests food in order to send the vital force absorbed from the food to other body parts). This type of explanation was of particular interest because science in pre-modern Japan was not biologically based, but vitalistic. To the extent that such explanations still reside within the culture, it was considered possible that Japanese children would frame their explanations within a vitalistic theoretical framework. For psychological problems, all participants chose mostly psychological explanations and some vitalistic explanations. For biological problems, children preferred vitalistic to biological explanations but never preferred psychological explanations. Adults preferred biological to vitalistic mechanisms for explaining biological phenomena. Based on these findings, Inagaki et al. suggested that children's performance on these tasks reflect a theory of biology that is separate from psychology, circumscribed by limited factual knowledge, and supplemented with a vitalistic theory.

To investigate the possibility that the above findings are particular to Japan, Miller and Bartsch (1995) replicated Inagaki and Hatano's study using American children who were English-speaking. They found that similar to Japanese children, American children had a theory of biology separate from psychology, but they rarely used vitalistic explanations. Cross-cultural studies, such as those conducted by Colin et al. (1999) and Miller et al. (1995) demonstrate that particular theories do not reflect universal constraints on knowledge acquisition. Such studies may also serve as an antidote to over-generalization, and may extend the range of variables that researchers should consider when studying development.

Other types of biological reasoning frequently discussed in the developmental literature on biological concepts include reasoning about illness (e.g., Kalish, 1996; Siegel, 1988) and about biological inheritance (e.g., Springer, 1992, 1995, & 1996). These two phenomena are observable, but can be explained by non-observable biological entities. The prevailing view once was that preschoolers are perceptually-bound and incapable of reasoning about non-observables (e.g., Piaget, 1970). With regard to illness, for example, young children were seen as knowing that certain behaviors lead to illness, but having no ideas of why or how (e.g., Bibace & Walsh, 1981). Current research not only refutes this idea, it has further demonstrated that children reason fairly competently about illness, considering their lack of technical knowledge. For example, preschoolers have been shown to understand that germs underlie the transmission of many diseases, and that contagion is domain specific in that you cannot catch things such as a scraped knee (Siegal, 1988). They also recognize that psycho-social forces, such as immanent justice, cannot explain why people catch diseases such as colds (Kalish, 1996; Springer & Ruckel, 1992).

In the quest to determine whether children explain biological phenomena in terms of biological or psychological mechanisms, kinship has recently been a topic of particular interest because it is a type of relationship that can be explained in biological terms (e.g., genes) and/or in psycho-social terms (e.g., care giving). From the child's perspective, the perceptual and psycho-social aspects of kin relations are easily observed: family members tend to look alike, live together, care for their young, share certain beliefs, and exhibit other social features (Springer, 1996). In contrast, the biological basis of kinship, genetic inheritance, is not immediately observable. Do preschool children have a perceptually-based and/or psycho-social construal of kinship, or do they also recognize its biological basis?

To date, there is no unanimity regarding the answer to this question. Springer suggested that preschoolers' concept of inheritance is biologically based rather than psychologically based (Springer, 1992, 1995a, 1995b; Springer & Keil, 1989, 1991). He conducted a series of studies designed to address four questions, including: (a) Where do children's biological theories originate? (b) How does the nature of a relationship (e.g., friend versus family member) influence children's thinking about the degree to which traits of different sorts are shared? (c) What types of traits can be inherited by offspring from parents?, and (d) What types of mechanisms underlie transmission of traits from parents to offspring?

With regard to the first question, Springer (1995) contended that young children's naive theories about kinship reflect inductive inferences from preexisting knowledge about prenatal growth. He suggests that basic knowledge about (a) where babies grow before birth, (b) how prenatal growth is relatively uninfluenced by external forces, and (c) the fact that physical proximity between two objects facilitates transmission of traits, is readily available to young children. Furthermore, this knowledge forms the basis for biological theories of inheritance. In one study, 4-, 5-, and 6-year-old children were asked a series of questions pertaining to basic knowledge about prenatal growth. Based on their answers, they were divided into high- and low-knowledge groups. Children in both groups were asked whether they endorsed ideas that reflect a biologically based theory of kinship. The particular ideas studied included the belief that babies share more stable properties with their mothers than unrelated individuals, that good and bad functional properties are equally inheritable, and that inheritance occurs by material transfer. Springer found that children who knew more basic facts of prenatal growth were more likely to express a biologically-based theory of kinship: virtually none of the children who expressed a biologically-based theory of kinship lacked this basic knowledge. Furthermore, providing information about prenatal growth to children who lacked this basic knowledge led to an increase in expression of a biologically-based theory of kinship. Overall, the results suggest that information pertaining to prenatal growth is readily available to young children and that theory building involves inferences from this basic biological information rather than a change from psychological to biological theoretical frameworks.

With regard to the question of whether the nature of the relationship influences children's thinking about the degree to which these individuals share traits, Springer (1992) presented children, aged 4- to 8-years of age, with pictures depicting a target animal and two other animals of the same species. One animal was unrelated but similar looking to the target and the other was related but slightly dissimilar to the target. Children were told that the target had a particular trait that is unusual, stable, and presumably with a genetic basis (e.g., hairy ears, tiny bones inside them, can see in the dark). They were asked whether the two other animals would also have this trait. For example, children were presented with the following information:

> Here's a duck. (Experimenter points to target). She can see in the dark. So when it's night time, she can see things outside. Here's another duck (points to similar duck). Even though this duck looks just like this duck (points to target), he comes from a different family. Do you think he can see in the dark like she can? Here's another duck (points to dissimilar duck). He's the baby of this duck (points to target). So even though they look different, he's her baby. Do you think he can see things in the dark like she can?

Children at all ages tested were more likely to induce properties amongst related animals that looked dissimilar to one another than unrelated animals that looked similar. When the unrelated animal was described as being a friend of the target, children still maintained that the target is more likely to share the unusual trait with the related animal rather than the unrelated animal. Thus, for children as young as 4 years, kinship outweighed similarity and species-ship in determining the extent to which biological properties are shared.

With regard to the question about the types of traits that can be inherited, Springer and Keil (1989) investigated whether children's intuitions about transmission of features would be affected by whether the features (a) were internal or external (e.g., pink heart versus big, stretched-out eyes), (b) were inherited or acquired after birth (e.g., Mr. and Mrs. Bull were both born with a pink heart versus Mr. and Mrs. Bull had an accident one time that made their hearts pink), and (c) had no effect on biological functioning (i.e., no consequences were stated) or did affect biological functioning. Features that affected biological functioning either had negative consequences (e.g., ...had a pink heart, so they weren't very healthy after that) or positive consequences (e.g., ...pink heart helps them stay healthy). Children's thinking about features that affected psychological functioning was also investigated. Again, these consequences were either negative (e.g., pink heart that made her feel angry a lot) or positive (white stomach that helps him be happy). Children between 4- and 8-years of age were presented with several pictures of animals depicting two parents and their baby. Both parents were described as having some type of abnormal feature that represented a combination of the characteristics outlined above (e.g., born with a pink heart that helps them stay healthy = internal, inherited, and positively affected biological functioning). For each picture, children were asked whether the baby would be born with the feature in its abnormal (e.g., pink heart) or normal form (e.g., red heart).

All children's responses were influenced by whether the trait in question affected biological functioning. Children were more likely to predict that the baby would be born with an abnormal trait if that trait affected biological functioning (positive or negative) than if it had no functional consequences. If a trait had psychological consequences (positive or negative), children seldom predicted that the trait would be inherited. In other words, children considered traits with biological consequences, not psychological consequences, to be inherited.

The internal-external dimension did not influence children's predictions, lending support to claims that they are not perceptually bound if they have a theory to guide their reasoning. One age trend that emerged, however, was the growing recognition of the importance of the inherited-acquired dimension. Around 6 years of age, children begin to understand that acquired traits are not inheritable. Before that age, children often think acquired traits can be transmitted from parents to offspring, but it should be noted that they hold this view only for traits that affect biological functioning. Therefore, although preschool children lack some information regarding some of the constraints on inheritance, they understand that the process of inheritance operates specifically over biological properties.

With regard to the question concerning mechanisms of inheritance, preschoolers have been shown to have reasonable expectations about the means by which biological properties are transmitted from parents to offspring (Springer & Keil, 1991). In a series of studies, children between the ages of 4- to 7-years were presented with three pictures, depicting a plant, animal, and artifact (can), respectively. They were asked to think about how each thing got its color. Each picture was accompanied with a list of causal mechanisms, which participants were asked to rank from worst to best as an explanation for its color. The types of explanations presented included (a) Intentional (e.g., "Maybe the baby flower turned blue because its mom wanted it to look like her when it came out. Because she wanted it to be blue so much, it turned blue."), (b) Gemmulic (e.g., "Maybe the baby flower turned blue because it got some tiny blue pieces from its mom. These tiny blue pieces went into the seed and made the baby flower turn blue."), (c) Genetic (e.g., "Maybe the baby flower turned blue because it got some tiny colorless things from its mom. These tiny things didn't have any color, but they could make the baby flower turn blue."), (d) Environmental (e.g., "Maybe the baby flower turned blue because the sun and rain kept the seed warm and wet. The warmth and the wetness made the baby flower inside turn blue."), (e) Chemical (e.g., "Maybe the baby flower turned blue because the sun and rain melted some blue color from its mom's petals that went into the seed and made the baby flower turn blue."), (f) Corpuscular (e.g.,"Maybe the baby flower turned blue because some very tiny pieces of sun and rain went into the seed and made it blue.") (g) Fanciful (e.g., "Maybe the baby flower turned blue because a little man came along with a paintbrush, opened the seed carefully, and painted it blue."), (h) Preformationist (e.g., "Maybe the baby flower didn't turn blue. It was always blue, even when it was so tiny inside the seed you couldn't see it."), and (i) Mechanical (e.g., "Whenever the gardener came out to watch the seed, he touched a lump of ground over the seed. Because he pressed this lump, something else happened and that made the baby flower turn blue.").

Most children considered the gemmulic explanation to be the best for the plant and animal, but ranked the mechanical explanation to be most appropriate for the artifact. In other words, the mother's contribution was preferred for dogs and plants and the contribution of human influence was favored for artifacts. Very few children understood the genetic mechanism, but when it was chosen, it was chosen only for biological entities. Children considered the fanciful explanation to be the worst, whether they were thinking about an animal, plant, or artifact, and also ranked intentions as being among the worst explanations, even for the artifact. While recognizing the importance of human intention in producing the artifact's color, it was considered insufficient; human action is also required. Overall, children as young as 4 years of age differentiated the types of causal mechanisms that are appropriate for biological entities and artifacts. These response patterns support Springer's contention that preschool children recognize the biological basis of kinship and realize that psychological mechanisms (intentions), although a salient aspect of kinship, are irrelevant to biological inheritance.

A number of researchers disagree with Springer's conclusions (e.g., Horobin, 1997; Solomon, Johnson, Zaitchik, & Carey, 1996). For example, Solomon et al. (1996) suggest that before the age of 7 years, children initially view families strictly as social units that are linked by proximity, common behaviors, and similar appearances. They further argued that before the age of 7 years, children have no sense of the mechanisms underlying parent-offspring similarity. In their study, children aged 4- to 7-years were presented with an adoption story where a boy was born to one man and adopted by another. The biological father was described as having one set of features, six features being physical (e.g., green eyes, tall) and six being psychological (e.g., believes skunks can see in the dark, likes candies more than pickles). The adoptive father was described as having the contrasting set of features (e.g., brown eyes, short, believes skunks cannot see in the dark, likes pickles more than candy). For each feature, children were asked who the boy would resemble, the biological or the adoptive father. Their responses were categorized into four groups: (a) "differentiated," which included those participants who judged the boy to resemble his biological father on most of the physical features but few of the psychological features and to resemble the adoptive father on most of the psychological features but few of the physical features; (b) "biological bias," which included participants who judged the boy to resemble mostly his biological parent on both physical and psychological features;

(c) “adoptive parent bias,” which included participants who judged the boy to resemble mostly his adoptive father on both the physical and psychological traits; and (d) “mixed,” including participants whose response patterns did not fit into the previous three categories. A differentiated response pattern was considered indicative of an adult-like, biological understanding of inheritance.

Not until the age of 7 years did children in the Solomon et al. study exhibit a differentiated response pattern. Before this age, most children exhibited a mixed response pattern. Thus, these researchers concluded that preschool children do not implicate birth as a process selectively mediating the acquisition of physical traits. Nor do preschoolers understand that learning and nurturance mediate the acquisition of psychological traits. That is, they do not distinguish biological from psychological mechanisms and do not seem to understand that only biological traits are inherited.

Springer (1996) questioned these conclusions, suggesting that the discrepancy between his and Solomon et al’s. findings were, in part, stimulus-driven. In the stories Solomon et al. used, the baby boy is described as being “adopted” by a king and then “becomes” a prince. Springer proposed that young children may not understand the terms “adopted” or “becomes” and that this information may bias some children toward believing that a special sort of change occurs in the adopted baby. To test this possibility, Springer (1996) used the story originally employed by Solomon et al. (i.e., “Original Story), and compared children’s reasoning about the situation described in that story to their reasoning about the situations described in two other types of stories. The “Modified Story” was identical to the Original Story, except the term “adopted” was replaced by "took him back to his house" and the term "becomes" was omitted. The "Switched at Birth Story," involved a situation where two babies from two families were unknowingly switched shortly after birth. A version of the Switched at Birth Story was used in a study by Hirshfeld (1994), who found that young children presented with this type of story consider race to be a stable property that does not change with cross-racial adoption.

Springer found that if preschool children understood the implications of birth to inheritance, they gave differentiated responses. Children 6 years and older provided differentiated responses, regardless of the type of story read to them. Preschoolers also respond differentially, but only for the Modified and Switched stories. When presented with the Original story, the findings replicated Solomon et al. (1996). These findings highlight the variability in performance that can be exhibited by the same individuals across superficially different, but conceptually similar tasks.

In a follow-up study, Springer (1996) investigated whether preschool children recognize that shared properties per se do not guarantee kinship. Of interest was whether children of this age understand that (a) a baby may neither resemble nor live with its biological parents, and (b) although a baby grew inside its biological mother, it may look like and live with a woman that is not its biological mother. Overall, results suggest that preschool children expect parents to share physical properties with their offspring, but also expect that there are some differences. Furthermore, they understand that shared properties do not necessarily guarantee kinship; one often shares properties with unrelated individuals of the same species. This appreciation of variability may underlie some deviations from the differentiated response pattern.

In summary, the issue of whether preschool children can be said to possess biological understanding has not been completely resolved. Of the researchers cited, most claim that preschool children meet the criteria of biological understanding in the sense that they can and do make critical biological distinctions (e.g., living versus non-living; the pertinence of biological mechanisms versus the irrelevance of psychological mechanisms to biological functioning). Some researchers challenge such claims (e.g., Carey, 1985, Solomon et al., 1996) and assert that children do not represent or reason about biological phenomena within a biological explanatory framework until approximately 7 years of age. In order for this issue to be resolved, further research is needed whereby children's reasoning about a variety of biological phenomena are investigated, using tasks that children can manage and find interesting. Such research may help demonstrate not only the extent of children's biological understanding (i.e., do they use biological mechanisms to explain all biological phenomena, or only a subset?), but may also provide valuable insights into how biological knowledge develops.

The developmental nature of biological understanding is also an unresolved issue, but one depiction that is common in the developmental literature is that of a stage-like transition from non-biological (e.g., psychological) to biological representations. Another candidate which I advocate is that of an overlapping wave model. This model was proposed by Siegler (1996) to account for the development of strategy use. Applying such an approach to the study of conceptual development, with its emphasis on variability of thinking, would enable researchers to ask interesting questions which are precluded by stage models. Stage models of conceptual development are discussed next, followed by a brief description the overlapping wave approach.

The Nature of Conceptual Development

Stage Model of Biological Concepts

In the current psychological literature, the development of biological concepts is depicted primarily within the framework of one of two stage models. Proponents of both models characterize the development of biological thinking in terms of a shift from non-biological to biological thinking, but vary in terms of when the shift is said to occur. In one version, children are described as conceptualizing biological phenomena within a psychological framework until approximately 7 years of age (e.g., Carey, 1985; Solomon, Johnson, Zaitchik, & Carey, 1996). Between the ages of 7- and 10-years, they come to understand biological phenomena as autonomous from psychological mechanisms. Use of psychological mechanisms to explain biological phenomena is replaced by use of specifically biological mechanisms. Thus during this period, children's biological understanding undergoes something akin to a paradigm shift from psychological to biological theoretical frameworks. In the other version, children are said to understand biology as an autonomous domain much earlier, at least by 4 years of age (e.g., Coley et al., 1999; Hatano & Inagaki, 1993; Springer, 1996; Wellman & Gelman, 1998). Figure 1 shows a representation of a stage model of biological understanding.

These portrayals are reminiscent of Piaget's model of general cognitive development whereby children are perceived as thinking or acting in a certain way for a prolonged period of time, going through a brief transitional phase, and then thinking or acting in a different way for another prolonged period. Within stage models, be they general or domain-specific, children's thinking is portrayed as monolithic at each age. The emphasis of research is on identifying sequences of correspondences between age and "the way children think at each age." Such descriptions of developmental sequences have a number of pragmatic virtues. They are simple, straightforward, and memorable, and call attention to the order in which change occurs (Siegler, 1996). They may also entail problems, however, as laid out by Siegler and Shipley (1995).

One problem inherent in stage models of development is the supposition that thinking within each stage is homogeneous. The premise of homogeneity in biological thinking is questionable because it is usually not the case that all children of a given age always think one way about biological phenomena (e.g., in terms of psychological mechanisms) and older individuals substitute this way of thinking with another way of thinking (e.g., in terms of biological mechanisms). Many preschoolers in Springer's (1996) study, for example, produced different types of responses, depending on the nature of the materials presented to them. Also, children's ratings for explanations of color depended on whether the entities being considered were biological in nature or artifacts (Springer & Keil, 1991). Finally, children and adults often express multiple ways of thinking across tasks (e.g., Siegler & Lemaire, 1997). Variability in thinking may be the rule rather than the exception.

The other problem associated with stage models, is that, as a consequence of their streamlined depiction of development, they may possibly impede our understanding the mechanisms underlying change. In fact, downplaying variability of thinking within each age group may prevent researchers from discovering important mechanisms of change. Furthermore, stages may simply be apparent, a consequence of the view that people are monolithic in their thinking at each point in development (Siegler, 1996). As Siegler (1996) noted, bringing variability to the forefront could have the effect of integrating change into the ebb and flow of everyday cognitive activity. It makes change a regular event that does not demand an exceptional explanation. For stage theorists, however, explaining change has been a particular problem. In addressing the question of "how" transitions occur, they have often been accused of being vague or silent.

In response to these problems, some researchers are attempting to transcend the search for correspondences between age and thought by focusing on variation and selection in cognitive development. A model that reflects this attempt is the overlapping waves model (e.g., Siegler, 1996; Siegler & Shipley, 1995).

Overlapping Waves Model

Within this model, individuals are assumed to use multiple approaches over prolonged periods of time. Figure 2 shows one possible depiction of the multi-variable ways biological phenomena may be construed at various ages. As can be seen, development is not portrayed as stepping up from Level 1 to Level 2 to Level 3. Rather, it is envisioned as an ebbing and flowing of the frequencies of alternative ways of thinking, with new approaches being added and old ones being used less often, or not all. The overlapping waves depict the relative frequencies of multiple ways of thinking at each point in time.

In the area of math, for example, Siegler (e.g., 1987) found that children use a number of different strategies to solve problems that measure a particular type of mathematical skill. Furthermore, after discovering an efficient strategy for solving math problems, children occasionally revert back to using less efficient strategies on other, similar problems. These findings highlight the variable nature of thinking within age-groups and contradict claims that older children think about particular phenomenon one way and that younger children think about the same phenomenon in another way. Perhaps conceptual change is best depicted as continuously changing frequencies of alternative ways of thinking, rather than substitution of one way for another.

Under traditional stage models of cognitive development, conceptual understanding has been described in terms of dramatic differences across age groups. Between-group variability typically receives much discussion while variability within groups, and certainly within individuals, has been relegated to the background (Siegler, 1996). Bringing the latter sorts of variability to the foreground has potential descriptive and explanatory value, however. With regard to description, knowing that multiple theoretical frameworks may be used to generate explanations, for example, makes clear the need to examine separately developmental changes in the frequency, accuracy, and breadth of applicability for each framework. This exercise can lead to a more differentiated description of development than would be obtained by averaging over different approaches.

Regarding explanation of conceptual development, overlapping wave models bring to the fore questions that have been overlooked by stage models. Because variability is considered the norm, questions generally pertain to choice. For example, what leads older children to choose different explanations than younger ones? Is it that some young children lack a theoretical framework in biology that is separate from psychology, or do they in fact possess such a framework but use different algorithms for choosing among frameworks than older children? Why do some individuals continue to choose a theoretical framework that provides either incomplete or incorrect explanations when they can choose explanatory mechanisms from better frameworks? How are new ways of thinking discovered? Once they are discovered, how are they integrated into the existing repertoire? How do cultural experiences affect choice? How does the nature of the stimuli used in tasks affect choice?

Conceived with an emphasis on multiple ways of thinking, my research is an attempt to describe children's and adults' explanations concerning when and how physical traits are transmitted. It is also aimed at describing their knowledge about the mechanisms underlying biological inheritance. I believe that some global, age-related differences in thinking about inheritance do exist and that in this study, age-related differences will be revealed. For example, unlike most adults, many preschool children are unaware of the genetic basis of inheritance. Furthermore, of the children who do know about genes, many do not have the same level of understanding of genetic mechanisms as that of adults. Similar to Siegler, however, I also believe that children's and adult's thinking are variable in nature and that traditional, global portrayals of conceptual development can be enriched by changing the foci from monolithic depictions of thinking to depictions emphasizing heterogeneity. Aggregating and averaging data concerning conceptions about inheritance would tend to result in a depiction such as seen in Figure 1, whereas focusing on variability would result in a much more differentiated portrayal, such as seen in Figure 2. To date, the actual shape and size of each wave shown in Figure 2 is not known because research that would permit precise depictions are lacking.

My research is a first step toward collecting information that would allow for a developmental model of biological understanding emphasizing variability to be outlined. I adopted Siegler's approach in the study of how inheritance is conceptualized by asking individuals several questions about inheritance, hence providing them with repeated opportunities to think about and explain transmission of traits. Due to the controversy surrounding "when" children can be said to possess biological understanding of biological phenomena, children from Grades 2, 4, and 6 were investigated in the current study. These ages, spanning from 6.8 to 12.1 years, represent the period of time during and after children are said, by some researchers (e.g., Carey, 1985), to switch from a psychological to biological framework. Children from younger age groups were also considered. In a pilot study, however, it was found that children younger than Grade 2 could not stay on-task for the entire interview. Although Siegler has generally been interested in studying variability to understand change in children's thinking, I extended his approach to the study of thinking in adults as well. Adults, who are often portrayed as being the end point of cognitive development (e.g., as possessing an understanding of genetics), may at times use non-genetic explanations to explain inheritance, and furthermore, may revert to using less advanced explanations (e.g., vague reference to a biological relationship). This research will help determine whether this possibility is the case. Understanding variability in adults will also provide a context for interpreting variability in children.

Variability in thinking about inheritance was addressed in my study by looking at two types of response patterns related to explanations. First, patterns of endorsements were addressed by asking the following question: When individuals are presented with several possible mechanisms for explaining inheritance of traits, how many explanations do they endorse, and what types of explanations do they endorse? Also of interest is whether endorsement is influenced by the nature of the entity (e.g., puppy, flower, pail) considered. Second, patterns of generation were addressed by asking: When individuals are presented with several questions that depict scenarios involving the concept of biological inheritance, how many different types of explanations do they generate and what types of explanations do they generate? Also of interest is how consistent they are in the explanations they generate. For both types of variability, my focus was on whether there are age-related changes in performance.

As suggested by the few studies that were focused on variability in other domains (e.g., Siegler, 1987), I expected diverse responding to be the rule, rather than the exception for individuals at all ages in the current study. I also expected individuals who possess an advanced understanding of inheritance (i.e., genetics) to use this knowledge and to rely on other forms of explanation with less frequency. Compared to other forms of explanation, an understanding of genetics allows one to predict more accurately which traits are inherited. It also enables one to explain inheritance more completely. Finally, it is the type of explanation taught most often in the science curriculum. Therefore, it is reasonable to expect individuals who understand genetics to depend on this form of explanation, and on others with less frequency. I also expect that as young children go through the science curriculum in school, they will acquire biological knowledge that may influence how they answer questions in this interview. For example, older children may know more about human physiology and animal life than younger children, and rely on this knowledge. Again, these expectations are suppositions that have not been investigated in previous research. The questions used in the interview are discussed in more detail in the Method section.

METHOD

Participants

Participants were 32 adults and 96 children. The adults were university undergraduates (M = 20.4 years; range = 17.8 - 31.1 years) from an introductory psychology course who participated to fulfill a course requirement. Three groups of 32 children in Grade 2 (M = 7.4 years; range = 6.8 - 8.3 years), Grade 4 (M = 9.4 years; range = 8.5 - 9.9 years), and Grade 6 (M = 11.6 years; range = 11.1 - 12.1) were from two Catholic schools in a middle class neighborhood in Edmonton, Alberta, Canada.

Procedure and Materials

All participants were interviewed individually in a quiet room. Interviews were between 45 minutes and 1 hour long, and were recorded on audiotape. The interview involved three components:(a) the Generation Task, (b) the Endorsement Task, and (c) Background Knowledge Task (see Appendix A for the interview booklet). In the Generation Task, participants were presented with a variety of items intended to elicit an explanation(s) about how physical traits are inherited across one or two generations. For questions in six items (items 1 - 6), participants were presented with a hypothetical situation related to inheritance and were required to predict an outcome. To respond, participants were asked to select an answer by choosing from a list of alternatives and then generate an explanation for their choice. For items 7, 8, and 9, participants were presented with an outcome (e.g., brown puppy), and were asked to generate an explanation for the outcome (e.g., Why do you think it is that this puppy is brown instead of a different color? What do you think caused this puppy to be brown?).

The Endorsement Task included three items (the second part of items 7, 8, and 9), designed to gather information about the types of mechanisms individuals think are responsible for color in three entities. As in Springer and Keil's (1991) study, two entities were biological in nature (puppy, flower) and one was an artifact (pail). For each entity, seven explanations were presented: genetic, environmental, psychological (i.e., intentions), theological (i.e., God), fantasy (i.e., fairies), vitalism, and preformationism. Participants were asked to give their opinion concerning the soundness of each explanation in the form of a rating (from very silly to very good). Endorsement was defined as choosing a good or very good rating.

The final three items were intended to assess three types of background knowledge: intuitive statistical knowledge, knowledge about of the role of the environment on the expression of traits, and knowledge about genes and the role they play in transmission of traits from parents to offspring. Information from these three items was gathered to help interpret the response patterns in the Generation Task and Endorsement Task. These items were presented last in order to avoid altering (i.e., cuing) participants' responses in the other two components.

For each item, the main questions were followed by response options, either in a Likert scale or multiple choice format. Participants were asked to respond to these questions by referring to the response options. Compared to "Yes" versus "No" type of responses usually requested in the research reviewed earlier, multiple options are likely to be more sensitive to variations in the types of responses participants could give. If participants were not sure of which option to choose, they were told that they could respond by saying "I'm not sure." They were also told that if they did respond this way, they would be asked what type of information they would need to answer the question.

After choosing an option, participants were then asked to justify their choice. Justifications can provide much information about the thinking that lies behind a choice. Furthermore, a request for justifications may encourage participants to think deeply about the particular issue of interest, perhaps for the first time (Ginsburg, 1997). If justifications were ambiguous, participants were encouraged to elaborate.

Next, the items are described briefly. Although the focus on my dissertation is on age changes in the number and patterns of explanations endorsed or generated, in describing each item I identify more specific issues that could be examined. Responses to each item are presented in Appendix C.

Items 1 and 2

In items 1 and 2, a picture of an adult female animal (e.g., dog) and two infants of the same kind (e.g., puppies) were presented. The adult was described as having a trait that is unusual in size for the species in which they belong. For example, in item 1, participants were told the following: "Here's a dog. She has very small ears. This kind of dog usually doesn't have such small ears." The trait in item 1 was external (very small ears) and thus perceptible in the drawing, whereas the trait in item 2 was internal (very large heart) and thus not perceptible.

The interviewer then pointed to one infant and described it as being the same type of animal as the adult. Participants were also told "He is the same color as this one [points to adult] but he is not her baby." Participants were asked to predict the size of the trait of interest (e.g., ears) that the infant would have when it grows up, using a 5-point Likert scale (1=very small, 2=somewhat small, 3=average size, 4=somewhat large, 5=very large). They were also asked to justify their predictions.

Next, the interviewer pointed to the other infant and told participants that "He is the baby of this dog [points to adult]. So even though he is a different color than this dog, he is her baby." Again, participants predicted the size of the trait that the baby would have when it grew up and justified their predictions. Of interest was whether participants, particularly young children, were appearance-bound when making their judgements. That is, would their choices be based on color or the relationship? Finally, participants were asked to explain why their predictions for the two infants were the same or different, depending on what their choices were on the previous two questions. For example, one possible question was "Why do you think that this puppy will have smaller ears than that puppy when they grow up?" After predictions and justifications were recorded, participants were asked to point to the baby of the adult. This memory check is sometimes prudent when interviewing young children.

Items 1 and 2 were similar to those used by Springer (1992), except that participants in this study could provide a range of predictions, whereas participants in Springer's study were given two choices (i.e., Yes–the baby will have the trait, No–the baby will not have the trait).

Item 3

In this item, participants were asked whether they think people generally look more like their friends or their parents. The focus was on stable and perceptible (i.e., physical) features such as eye color and facial structure rather than changeable features that can be influenced by current trends (e.g., hair style, type of clothes). Participants responded, using a 5-point Likert scale (1=much more like their friends, 2=a little more like their friends, 3=equally like their parents and friends, 4=a little more like their parents, 5=much more like their parents). They were also asked to explain their choice. For example, if participants indicated that they thought that people looked a little more like their friends, they were asked "What do you think causes people to look a little more like their friends than their parents?" This question provided participants with an opportunity to explain how traits could be shared among unrelated individuals (e.g., we tend to pick friends that look like us, but we can't choose our parents).

Next, participants were asked whether they thought people generally look more like their parents or grandparents, again focusing on permanent and obvious physical features. Participants responded, using a 5-point Likert scale (1=much more like their grandparents, 2=a little more like their grandparents, 3=equally like their parents and grandparents, 4=a little more like their parents, 5=much more like their parents). They were also asked to explain their choice. This question was designed to provide information as to whether participants recognize that the degree of relatedness (e.g., first generation kin versus second generation kin) determines the degree to which traits are shared among individuals.

Item 4

Item 4 was designed to investigate whether participants understand the implications of birth to biological inheritance. Participants were presented with a picture depicting an infant and two adult couples. One couple was very tall, the other was very short. Participants were told the following: "Here is a baby girl, and here are both of her parents (interviewer points to very short couple). Notice that her parents are very short. The baby girl doesn't live with her parents. Instead, right after she was born, she moved in and grew up living with this couple (interviewer points to the very tall couple). Notice that this couple is very tall." Participants were asked to predict how tall the baby girl will be when she grows up, using a 5-point Likert scale (1=very short like her parents, 2= somewhat short, 3=average height, 4=somewhat tall, 5=very tall like this couple) and to justify their choice. If participants did not choose 1-very short like her parents, they were asked, "Why don't you think the baby will be very short like her parents when she grows up?" If participants did not choose 5-very tall like this couple, they were asked, "Why don't you think she will very tall like this couple when she grows up?" After all questions in this item were answered, participants were asked to point to the little girls parents and then to the couple that she grew up with.

This item is similar in intent to the stories used by Springer (1996) and Solomon et al. (1996). The word "adopted" was not used, because as Springer suggested, it is not clear if children understand the meaning of the term. Again, participants were permitted to choose from a range of options, rather that respond by choosing either "tall" or "short".

Item 5

Item 5 was designed to determine whether participants recognized that acquired traits are not transmittable from parent to offspring before birth. In other words, this item was designed to identify individuals who endorse a Lamarkian view of inheritance.

Participants were shown a picture of a couple with blue hands and were told the following: "Here is Mr. and Mrs. Jones. They work in a paint factory. Their job has caused their hands to be permanently stained with blue color. So now, their hands are blue instead of their normal skin color. They are about to have a baby." The participants were then asked to indicate what color of hands they thought the baby would have when it is born by choosing from among the following options: (a) blue; (b) skin-colored; (c) either blue or skin-colored, or; (d) not blue and not skin colored, but a different color instead. They were then asked to justify their choice. Choice (a) is consistent, but does not guarantee a Lamarkian view. For example, participants may choose (a) and justify their response by saying that the parents touched the baby as it was being born and the paint rubbed off. Participants who did not choose (a) were asked "Why don't your think the baby's hands will be blue?" This probe was particularly useful in clarifying their response.

Item 6

Item 6 was intended to assess whether participants understood that both parents contribute to the traits of their offspring. It was also designed to identify a sex-bias in responding. That is, would participants think that fathers contribute more traits to their sons than their daughters and that mothers contribute more traits to their daughters than their sons? Participants who are perceptually bound might demonstrate such a bias.

A picture of a female adult with blue eyes and male adult with brown eyes was presented (Mr. and Mrs. Smith). Participants were told that this couple has a son and were asked to say what color of eyes they thought he would have, choosing one of four options: (a) brown; (b) blue; (c) either brown or blue, or ; (d) not brown or blue but a different color instead. Each option was accompanied by a picture depicting a boy with each of the possible eye colors. They were asked to explain their choice. Next, participants were told that the couple had a daughter and again were asked to say what color of eyes she would have and to explain their choice. If participants gave different responses for the son and daughter, they were asked to explain why. Also, if participants gave a definitive response (e.g., blue), they were asked if it was possible that the offspring have eyes of a different color and why.

Participants were then presented with another adult couple (Mr. and Mrs Blake). In this case, Mrs. Blake had brown eyes and Mr. Blake had blue eyes. The questions following the presentation of Mr. and Mrs. Blake were identical to the questions asked for Mr. and Mrs. Smith. Also, they were asked to explain their response patterns across the two couples, unless they appeared to be making random choices or giving responses based on personal experiences (e.g., My mom's eyes are blue and mine are brown).

Items 7, 8, and 9

These items were designed to assess ideas about possible causal mechanisms underlying a trait (color) for 3 types of entities. Two entities were biological (animal-brown puppy; plant-pink flower) and one entity was non-biological (red pail). For each entity, participants were presented with a picture and were asked why they thought it was that color. For example, for the pink flower, they were asked, "Why do you think that this flower is pink instead of a different color? What do you think caused this flower to be pink?" Then they were told that they would be presented with some ideas for how the flower got its color and that they would be asked to say what they thought of each idea using a 5-point Likert scale. The instructions were as follows: "If the idea sounds silly to you, choose #1-very silly, or #2-pretty silly. If the idea sounds good to you, choose #4-pretty good or #5-very good. If the idea sounds partly silly and partly good, choose #3-not silly and not good. You should also choose #3 if you don't know or are unsure if the idea is silly or good."

Seven types of causal mechanisms were presented, including: (a) Preformation (e.g., Maybe it was a pink flower right from the beginning when it was inside the seed. Even when it was so tiny inside the seed that you couldn't see it, it was a pink flower.); (b) Fantasy (e.g., Maybe the flower was pink because a fairy sprinkled pink fairy dust on it before it bloomed.); (c) Intentional/Psychological (e.g., Maybe the flower bloomed pink because the gardener who planted it wanted it to bloom pink.); (d) Environment (e.g., Maybe something around the flower, either before or after it bloomed, caused it to be pink.); (e) Vitalism (e.g., Maybe the petals of the flower wanted to be pink.); (f) Genetic (e.g., Maybe the flower got tiny things from its parents, and these things contained instructions for the flower to be pink); (g) Theological (Maybe God chose pink for the flower.). After rating each causal mechanism, participants were asked to explain their choice. If it was apparent from their explanations that they misunderstood the nature of the causal mechanism (e.g., they interpreted the intentional-psychological mechanism in terms of selective breeding rather than in terms of changing the color simply by wanting a different color), they were informed of the intended interpretation and were again asked to indicate what they thought of the idea using the Likert scale.

These items were similar to those used by Springer and Keil (1991), except some of the wording was changed. For example, the psychological mechanism for the flower was changed from "Maybe the baby flower turned pink because its mom wanted it to look like her when it came out" to "Maybe the gardener who planted the flower wanted it to be pink." It is possible that children don't think intentional forces have an effect on color, that plants don't have parents, or that plants don't have thoughts. The wording was changed to distinguish these three ideas. Like the genetic prompt used by Springer and

Keil (1991) the term "genes" is not present in the genetic prompt used in the current study. Instead, a simplified description of genes, found in a pilot study to be understandable to young children and which was technically correct, was employed.

Included in the current study, but not addressed by Springer and Keil (1993) were vitalistic explanations. Recall that Inagaki and Hatano (1993, 1995) investigated Japanese children's interpretations of biological phenomena to determine whether their ideas reflect their cultural history, which at one time was vitalistic, not biologically based. They found that indeed, many children did express vitalistic ideas. Because of the multiethnic nature of Edmonton's population, it was considered possible that these ideas could be expressed.

Finally, another change was in the manner children were asked to respond. Children in Springer and Keil's study were asked to rank order the mechanisms from worst to best. The approach used in the current study allows children to choose more than one "best" mechanism. For example, it is conceivable that children believe that genes cause color in flowers, but also believe that God choosing the flower's color is an equally good explanation.

Item 10

Item 10 was designed to assess individuals' ideas about homogeneity and variance of traits. People who do not recognize variation amongst entities may make different predictions concerning inheritance of traits than those who do realize that entities vary. The traits investigated were identical to those studied by Nisbett, Krantz, Jepson, and Kunda (1993). One of the traits investigated (color of a particular species of bird) tends to be similar across instances, but there is usually some variability as well. The second trait investigated (weight) is inherently quite variable. The final trait investigated (the color of smoke emitted from a pure element) is inherently invariable. For the bird, participants were presented with the following scenario: "Imagine that you are an explorer who has landed on an island in the South Pacific. First, you see a bird called a Shreeble. It's female and blue. (A picture of a blue bird is presented). After seeing this one single female Shreeble, about how many of the other female Shreebles on the island would you guess are also blue." They were asked to choose from among the following options: (a) none of the female Shreebles on the island are blue, (b) less than half, (c) about half, (d) more than half, or (e) all of the other female Shreebles on the island are blue. Each option was presented with a visual cue (a circle that was empty, 1/4 blue, ½ blue, 3/4 blue, or all blue, respectively). They were asked to explain their choice. This approach varies from the one adopted by Nisbett et al. (1993) in that participants in their study were not presented with response options. Instead, they used an open ended format such as "What percent of all shreebles on the island do you expect to be blue?" Their format was not adopted because it was believed that young children would not be familiar with the concept of percentage.

Concerning the trait of body weight, participants were presented with a picture of a man who was native to the island. The man was depicted and described as having a rather heavy build. For the chemical element, participants were told that a scientist had come to the island and was burning a mineral, Cartium, that is found only on the island. They were also told to imagine that they saw the scientist burn the mineral and that it gave off bright purple smoke. For both traits, participants were asked to guess how many other instances on the island would share the trait.

Item 11

Item 11 was designed to assess individual's ideas about the impact of the environment on the expression of two types of traits. For one type of trait, height, the expression (i.e., phenotype) can vary within populations and within one's lifetime. Furthermore, height can vary as a result of relatively normal environmental fluctuations. For highly canalized traits, such as number of arms at birth, only one phenotype exists (i.e., two arms) except under extremely aberrant environmental situations (e.g., fetal exposure to high levels of nuclear fallout).

To ensure that all participants defined "the environment" similarly, they were presented with the following information: "Many people study the environment–which includes a lot of different kinds of things around us. The environment includes the different kinds of people around us and how they make us feel. It includes different things around us, like the weather, the types of foods available to eat, the quality of air and water, and the amount of noise around us. People who study the environment can even look at the environment that surrounds a baby in its mother before its born. So, all these things are part of the environment."

After this description was read, each participant was asked if they understood what the interviewer meant by the term "environment." They were then asked whether they thought anything in the environment could affect how tall people grow up to be. If they responded "yes", they were asked "What kinds of things in the environment can affect how tall people grow up to be?" and "How much do you think that the environment can affect how tall people grow up to be?" To the latter question, they were asked to respond using a 4-point Likert scale (1=little effect, 2=some effect, 3=much, 4=complete effect) and to justify their choice. If they responded "no", that is, nothing in the environment can affect how tall people grow up to be, they were asked "Why not?" A similar series of questions was then asked for the canalized trait. If participants gave different answers for both traits, they were asked to explain the differential response pattern. If they indicated that they did not believe the environment could affect either trait, they were asked to explain why.

Item 12

Item 12 was designed to assess whether participants had an awareness and understanding of the concept of the gene. First, a card with the word "gene" written on it was placed in front of participants. Then, they were asked if they have ever heard of genes. It was emphasized that the interviewer was not interested in jeans, an article of clothing, but instead something they may have heard about in their science classroom. If they responded "no", the interview ended. If yes, they were asked "What do you think they do?", "What kinds of things have genes?", "Where we get our genes from?", "Where genes are found?" and, "Is it possible to see a gene?" These questions were used to determine whether in fact they did know what genes were and if so, how much they knew about genes.

Justifications

Participants' justifications to all questions were classified into five major categories: (a) congruous with biological theories and with a clear causal mechanism, (b) congruous with biological theory but without a clear causal mechanism, (c) psychological or behavioral, (d) theological, and (e) non-causal. Justifications were further classified into subcategories, when possible. Depending on the number of distinct ideas included in a justification, it could be assigned one or more subcategory.

Categories and subcategories were partially based on expectations of the types of responses that were deemed to be possible. They were also partially based on the actual responses generated that were not anticipated. Categories and subcategories, along with examples of characteristic responses are provided in the next section. Note that many of the examples included below would be given two or more codes.

Explanations That Are Congruous with Biological Theory of Inheritance-Clear Cause

These explanations contain ideas that are often incorporated in scientific theories of inheritance and include a mechanism that enables traits to be shared among members of the same species or family.

Genetic. Responses were coded as genetic if explicit reference was made to the genes, DNA, or chromosomes. Elaborations concerning dominance, recessiveness, or co-dominance were also coded if mentioned (e.g., Genes were passed on and made her ears small.)

Genetic-Related Responses. Responses were given this code if they included ideas that may also be included in scientific theories of inheritance, but did not include the words "genes" "DNA", or "chromosomes". Examples of such ideas include inheritance (The mother passed the traits on to her baby. The baby inherited small ears from its mother.), evolution (e.g., They evolved the same way.), and predetermination (e.g., The blueprint for it was to be pink.).

Physiological. Responses categorized as physiological included references to some physiological mechanism of trait transmission (e.g., Paint may soak through the skin. The puppy rubs against the mother's tummy–which is brown. It is passed on through the blood).

Environmental. Responses were coded as environmental if a reference was made to environmental factors or if the word "environment" was included. Participant often provided specific environmental causes (e.g., food, emotional environment, religious environment, culture, season).

Explanations That Are Congruous with Biological Theory of Inheritance-Unclear Cause

These were responses that made reference to important biological prerequisites of inheritance (e.g., kinship, species-ship, birth). When participants' responses omitted a clear causal mechanism, (e.g., She is the mother), they were classified into this category. When a clear causal mechanism was included with this information (e.g., She is the mother so he will get her genes.), the response was given this code plus the causal mechanism (e.g., Kinship (mother)-Genes). In Tables 3, 4, and 5, data under "Congruous with a biological theory-unclear mechanism" includes only those responses that omit clear causal mechanisms. "Growth" was also included in this category, because it is biological, but it is not clear how growth can enable traits to be shared amongst kin or members of a species.

Kinship. Responses were given this code if participants alluded to nature of the relationship between kin. Included were references to parents, grandparents, siblings, etc. (e.g., That's the puppy's mother).

Species-ship. Responses were given this code if participants alluded to species. Included in this category are the ideas "same kind", "same type", or "species." (e.g., They're the same kind of horse.)

Growth. Responses were given this code if participants expressed the idea that traits are a result of natural growth processes (e.g., He will grow up to be like his mother.)

Birth. Responses were given this code if participants said that birth or being born to parents with a particular trait results in the traits being shared with the offspring. Conversely, responses that include the idea that not being born to a couple with an unusual trait makes it unlikely that the trait will be shared were also give this code (e.g., He wasn't born to that dog, so he won't have small ears.).

Psychological or Behavioral

Responses were coded as psychological if it was conveyed that wishes, intentions, thoughts, and/or beliefs alone could result in certain traits (She wanted to be tall like them). If responses included a voluntary action that was a consequence of these psychological phenomena (e.g., He wanted a red pail, so he painted it red.), they were coded as behavioral.

Theological

Responses were given this code if reference was made to divine intervention. Typical responses included "God."

Noncausal Explanations

These were generally observational type of responses that lacked a clear causal mechanism, including statistical, analogical, anecdotal, and perceptual responses.

Statistical. Responses were given this code if participants referred to averages (e.g., most individuals of that kind possess the trait, it's normal for...., it's not supposed to be....), variation between individuals (e.g., children don't look exactly like their parents), and reference to the fact that some traits are correlated with other things (e.g., Blond hair and blue eyes go together. She has blond hair, so she'll have blue eyes.).

Analogical. Responses were coded as analogical if they involve a comparison to other similar situations with which participants are familiar (e.g., People have ears like their mother, so the puppy might have ears like its mother.)

Anecdotal. Responses were coded as anecdotal if they made reference to personal observations (e.g., my mom has blue eyes, my dad has brown eyes, and my brother has brown eyes).

Perceptual. Responses were coded as perceptual if traits were explained solely in terms of perceptual factors (e.g., the yellow puppy will have small ears because the big dog is yellow and has small ears).

Indeterminate and Not Sure

When responses were too ambiguous to categorize into the above categories (e.g., (e.g., That answer sounds right to me.) they were categorized as indeterminate. When participants replied with, I don't know, or I'm not sure, this response was coded as not sure.

Multiple Codes

As noted previously, responses that included more than one distinct idea were given more than one code. Examples of coded responses include: Maybe her parents gave her better food = **Kinship** (parents) and **Environment** (food); His mother is the same type as species as he is and gave him her genes = **Kinship** (mother), **Species-ship**, and **Genes**; She wants to be like her mother, so she will grow to be tall like her = **Kinship** (mother), and **Psychological.** Many responses contained more than one distinct idea.

Reliability of Coding

The principal investigator coded the responses of all the participants. A second coder was trained and coded read and coded 31 % of the response booklets. Reliability was quite high, agreement was achieved on 91 % of all responses.

RESULTS

The Generation, Endorsement, and Background Knowledge Tasks are examined in the reverse order in which they were presented to participants; the Background Knowledge Task is discussed first, followed by the Endorsement Task, and finally, the Generation Task. As outlined in the Method section, reviewing responses in the former sections helps shed light on participants' thinking in the latter sections.

Background Knowledge Task

Of interest in the current study was not only whether participants possessed knowledge about genes, the environmental impact on the expression of traits, and variation of traits, but their inclination to use this knowledge. Because I consider "genes" to be the most important idea in current scientific theories of inheritance, followed closely by the idea that the environment can affect the expression of traits to varying degrees, participants' knowledge of these two ideas is discussed before their intuitions about natural variation.

Discussion of the responses in Background Knowledge Task is organized around the following questions: (a) Are there age-related differences in the number of individuals who recognize the term "gene" and who have knowledge that is consistent with current scientific views about genes and their functioning? (b) Are there age-related differences in the number of individuals who exhibit a sensitivity to the differential effects of the environment on highly variable and highly canalized traits, and who can give responses that are consistent with current scientific views about the environmental affects trait expression? If so, how do the age groups differ? (c) Does the extent to which individuals generalize a property from a single observation depend on the natural variability of the property? If so, are there age-related differences in participants' willingness to generalize properties?

Age-Related Differences in the Concept of Gene

Although the majority of the questions in the interview concerned inheritance, and therefore genes, participants were not explicitly cued to use their knowledge about genes until the final item (see Appendix A: item 12). This item comprised a series of questions devised to determine the amount of knowledge participants had about genes and whether this knowledge remained inert when responding to the preceding questions.

It is presumed that if experts were given this item, they would have indicated in their responses that (a) they had heard of genes, (b) genes contribute to one's looks, behaviors, and intelligence, (c) genes are found in all living things (i.e., plants and animals, including people) and not in non-living things (i.e., things that were never alive), (d) genes come from our ancestors, (e) genes are found in every cell that has a nucleus, and (f) genes could be seen with the aid of a powerful (i.e., electron) microscope. Participants' responses were compared to these hypothetical responses to establish whether their knowledge was consistent with the views of an expert, and to determine the degree to which their knowledge is included all the above ideas (i.e., degree of completeness).

The first question in this item was Have you ever heard of genes? Only those who indicated that they had heard of genes were given the follow-up questions. Responses from the follow-up questions were used to determine if in fact participants did have knowledge about genes and the extent of their knowledge; it is possible that individuals had heard the term "genes" without knowing what they are or what they do. Participants who said yes to the first question, but responded to the follow-up questions with "I don't know" or "I'm not sure," were considered to lack knowledge about genes. Responses to questions 12b, 12c, and 12d were considered critical to claims that participants had knowledge of genes. Because of the centrality of the living-nonliving distinction in biological understanding, participants must have indicated in their response to question 12c that genes are found only in living things. If they said that genes were found in non-living things, they were considered to lack knowledge about genes. Finally, unless they had knowledge about the function (question 12b) and origin (question 12d) of genes, their knowledge was considered to be superficial. In this study, to be considered truly "knowledgeable," participants had to indicate correctly where genes come from (e.g., ancestors) and provide at least one function of genes. The last two questions in item 12 (Where are genes found? Is it possible to see a gene?) were included to determine the extent of their knowledge about genes, but were not considered relevant to claims about whether they did or did not know what genes are.

For each question in this section, age effects on knowledge were analyzed using Pearson chi-square tests. Age group (Grades 2, 4, 6, adult) was crossed with knowledge (e.g., Does this person think that plants have genes?: Yes, No). When the chi-square test was found to be significant ($\alpha = .05$), further analyses were performed to establish which groups differed in terms of knowledge. Specific group comparisons (e.g., Grade 2 versus Grade 4) were also analyzed with Pearson chi-square tests. To reduce the probability of Type I error, the alpha level for each specific comparison was set at .01.

Knowledge about genes varied across age groups. Table 1 shows the frequency of different responses to each question in item 12. In response to Have you ever heard of genes?, the frequency of participants who said "Yes" increased with age, $\chi^2(3, N=128) = 47.41$, $p < .001$. Five children in Grade 2, 16 children in Grade 4, and 19 children in Grade 6 claimed to have heard of genes. Upon further questioning, however, it became apparent that not all of these children actually had knowledge about genes. Only one child in Grade 2 provided answers that met the criteria listed above. Another child in Grade 2 used "DNA" in his answer, a concept he acquired from watching the movie, *Jurassic Park*, but he said that DNA was something you buy at a computer store. The remaining three children in Grade 2 replied to the follow-up questions with *I'm not sure* or *I don't know*. Thirteen and 16 children in Grades 4 and 6, respectively, had knowledge about genes, and all university students met the criteria for knowledge about genes. Participants who were considered to lack knowledge about genes were excluded from further analysis.

When asked What do you think genes do?, almost all participants who had heard of genes stated that genes are responsible for how one looks (see Table 1). Adults tended to express this idea with a more sophisticated language, using terms such as "blueprint," and "codes for," whereas children tended to use phrases such as "They make you look the way you look." (S28: Second Grade). The proportion of participants who mentioned that genes determine intelligence or behaviors varied across age groups, χ^2 (3, N=62) = 9.44, $p < .05$, with adults referring to these characteristics more often than children ($p < .005$). It should be noted, however, that almost a third of all adults did not include intelligence or behaviors in their response. It should also be noted that none of the participants who excluded these characteristics from their response actually said that genes do not affect behaviors and intellect. Their omission may reflect the fact that, in the scientific community, there is much debate concerning heritability of behavioral tendencies and cognitive capabilities. Therefore the genetic contribution to these characteristics might not be emphasized in the classroom or in any other source of information on genetics (e.g., T.V.). Finally, adults sometimes included in their answer information regarding cellular processes (e.g., "during meiosis, DNA splits...."), whereas children never volunteered this information.

In response to What kinds of things have genes?, all participants who had heard of genes said that people have genes, and almost all of these participants stated that all animals have genes. The proportion of participants who mentioned plants in their answer varied with age, χ^2 (3, N=62) = 9.80, $p < .05$. There was an increasing tendency with age to include plants in response to this question ($p < .05$). All of the individuals who omitted plants from their answer said that plants do not have parents earlier in the interview (see Appendix A: item 8). Perhaps for this reason, they may not have considered genetic transmission to be applicable to plants.

In response to Where do we get our genes from?, the proportion of participants who answered in terms of "parents" versus "ancestors" varied slightly with age, but this difference did not reach significance. Children frequently responded in terms of ancestors. The one child in Grade 2 who knew what genes were said they come from our ancestors (e.g., "They come from your parents and their mom and dad." S28). Also, over half of the children in Grades 4 and 6 who knew about genes phrased their response in terms of ancestors (e.g., "They come from your parents, who got them from their parents, who got them from their parents...." S45:Grade 4). The remainder responded by saying that parents are the source of genes. It is possible that these children knew that genes originate in our ancestors, but focused on parents because the questions in the interview were concerned primarily with inheritance across one generation. Most adults also responded in terms of parents instead of ancestors, perhaps for the same reason.

In reply to Where genes are found (in the body)?, the child in Grade 2 said they were found in the "blood in the whole body." A number of children in Grades 4 and 6 did not know the answer to this question, and a few responded in terms of body parts (e.g., "They're found in the stomach area." S44:Grade 4). The majority of children who knew about genes stated that genes are found in the whole body. Almost all adults also stated that genes are found throughout the body, but tended to be more specific than children by stating that they are found in all cells. Only a few adults gave less sophisticated responses (e.g., "They're found all over the body." S115) or did not know the answer to this question.

Finally, when asked Is it possible to see a gene?, the Grade 2 student said "Yes, with a strong microscope" (S28). Over half of participants from Grades 4, 6, and university also stated that it is possible to see genes. When asked how, the majority of participants in these age groups stated "with a strong microscope" but a few children answered in terms of phenotype (e.g., "you can see genes by looking at how people look, like their eye color." S61: Grade 4). When the participants who said it was not possible to see a gene were asked why not, they responded in terms of either "They're too small" or "not sure."

In summary, fewer children than adults possessed core knowledge of genes. In some respects, children who knew about genes were comparable to adults in their knowledge about genes. In particular, they knew where they came from, that people and other animals possess genes, and that genes partially determine how we look. In other ways, their knowledge was less inclusive in that fewer children said that genes are found in plants and that they code for intelligence or behavior. Finally, children lacked knowledge about cellular processes related to genetic replication and transmission. Based on the pattern of answers to the questions in item 12, it should be expected that in the Endorsement Task, fewer children than adults would accept the genetic mechanisms, especially in the context of the plant. In the Generation Task, children who lack knowledge about genes would not be expected to generate genetic explanations. Finally, those who lack knowledge about certain aspects of genes would not likely see the applicability of genetic mechanisms to all questions in items 1 to 8.

Age-Related Differences in the Concept of the Environment

The environment plays a central role in scientific theories of inheritance. The questions in item 11 were designed to assess individual's thinking about the impact of the environment on the expression of two types of trait. One trait (i.e., height) varies and can be influenced by relatively normal environmental fluctuations. The other is a highly canalized trait (i.e, number of arms) that does not vary, except under very unnatural environmental circumstances (maternal ingestion of thalidomide during pregnancy).

If experts were presented with these questions, it is presumed that they would indicate that a highly variable trait such as height is affected by the environment. The size of effect, however, is more difficult to predict, because there is much controversy surrounding the size of impact of environment versus genes on the expression of traits. "Complete effect" would not be chosen, because that option rules out the contribution of genes to height. Experts could endorse any one of the three remaining options. For the highly canalized trait, experts would also say that environment could affect its expression. Reports of environmental causes of fetal aberrations are known and have been widespread during certain periods in history (e.g., thalidomide effects or nuclear radiation effects on physical and cognitive traits). Because highly canalized traits are very difficult to alter by environmental manipulation, experts would likely say that the environment would have little effect on their expression.

For each trait, two questions were of particular interest. With regard to height, for example, participants were asked: Do you think that anything in the environment can affect height? and How much do you think that the environment can affect height? Responses were analyzed separately, using Pearson chi-square tests ($\alpha = .05$) with group (Grade 2, Grade 4, Grade 6, adult) crossed with response (i.e., "Yes or No" for the first question; "Little Effect," "Some Effect," "Much Effect," and "Complete Effect" for the second question).

As seen in Figure 3, there were no age-related differences in the frequency with which individuals said that the environment could influence height. Most participants in all age groups (overall proportion = 87%) agreed that height can be influenced by the environment. On the follow-up questions, age effects were analyzed for each response option (e.g, "Little Effect") separately. The number of participants who chose each response option was not affected by age. Almost half (46%) of all participants chose "Some Effect" and most of the remaining participants (46%) chose either "Little Effect or Much Effect." Only 8% of all participants who said that the environment affects height said that the environment has a "Complete Effect." Examples of environmental factors that could affect height included food or pollution. When asked if there were other factors that could influence height, 53% of adults but only one child mentioned genes.

Belief that the environment can influence a highly canalized trait (i.e., number of arms), varied across age, χ^2 (3, $\underline{N}$=128) = 17.75, $\underline{p} < .001$ (see Figure 4). More adults (78%) than children (overall proportion = 30%) ($\underline{p} < .001$) stated that the environment can influence number of arms. Generally children in all three grades tended to think that such traits are immutable or at least very difficult to change by environmental factors. As many children explained, people who have more than or less than two arms are rare. Adults who said the environment has no effect gave the same types of answers. Of the adults who did believe that the environment can affect number of arms, 75% said that it has only little effect, and only in extreme circumstances.

Overall, most participants agreed that height can be influenced to some extent. With regard to the highly canalized trait, participants seemed to share the view that "normal environmental fluctuations" would not affect the number of arms people are born with. Children were more adamant in the sense that they said that nothing in the environment can affect number of arms. Adults tended to say that the environment could affect number of arms, but qualified this response by saying that the environment would have this effect only in very abnormal conditions. Otherwise, they said, the environment has no effect on this trait. Because the traits investigated in the current interview can vary within populations, it would be reasonable to expect that adults and children would be similar in terms of their endorsement of the environmental mechanisms in the Endorsement Task and in terms of number of environmental explanations generated in the Generation Task.

Age-Related Differences in the Concept of Natural Variability

Of interest in item 10 were whether (a) participants would be less willing to generalize a property from a single observation when variability rather than homogeneity is expected, (b) justifications would reflect statistical intuitions, and (c) this intuition develops. Nisbett et al. (1993) found that adults were most willing to generalize a property that was inherently invariable (color of smoke emitted from a pure element that was being burned), and least willing to generalize from a trait that is quite variable (weight of men on an island). The extent to which they generalized a property of intermediate variability (color of a particular species of bird) was less than that for color of the element, but more than for weight.

Each characteristic was analyzed separately (e.g., color of female shreeble). The frequency with which participants selected options "a" (i.e., none of the other female shreebles are blue) through "e" (all of the other female shreebles on the island were blue) were tabulated. For this dissertation, the number of individuals in each age group who chose "more than half" or "all" were combined into a single category (simply called "willing to generalize to more than half of the cases"). Age effects were analyzed using Pearson chi-square tests ($\alpha = .05$), with age group crossed with "generalize trait to more than half of the cases on the island?" (Yes, No).

As seen in Figure 5, the pattern of responses given by participants in the current study was similar to those of Nisbett et al. (1993), regardless of age. Even children recognize that one must be cautious not to overgeneralize a trait (i.e., generalize a trait to the more than half or all other cases) that is quite variable, but that this level of caution is not necessary for fixed traits. However, there was an effect of age for color of bird χ^2 (3, N=128) = 8.90, $p < .05$, weight of man, χ^2 (3, N=128) = 8.06, $p < .05$, and color of smoke from rock χ^2 (3, N=128) = 11.23, $p < .01$. Adults were more willing than children to generalize properties from a single instance, whether they were thinking about color of birds, ($p < .01$), weight of people on an island, ($p < .005$), or color of smoke emitted from a burning element ($p < .005$). In other words, when asked to specify how many other cases on the island would share the property in question, adults generally chose higher proportions than children. It is not clear why adults would be more willing than children to generalize from one observation.

As seen in Figure 6, most participants generated a statistical response at least once in this item (e.g., "He's a human and humans are different from one another." S64: Grade 4; "This is a characteristic of the bird, but by chance it could be a different color." S127: Adult), but there was an effect of age, χ^2 (3, N=128) = 11.89, $p < .005$. Children in Grade 2 generated this type of answer less frequently than the other three age groups ($p < .001$). Five children in this grade never generated a statistical response whereas almost all individuals in each of the other age groups generated a statistical answer. Furthermore, there was an age effect on use of statistical ideas for all three properties, χ^2 (3, N=128) = 14.18, $p < .005$. Compared to participants in other age groups, fewer children in Grade 2 consistently generated a statistical response for all three properties ($p < .005$). In their justifications, individuals within all age groups mentioned variance and homogeneity (i.e., lack of variance). Adults also referred to statistical chance and the small sample size.

In summary, knowledge about variability and homogeneity was revealed by all participants, except five children in Grade 2. Thus, it should be expected that statistical responses would be prevalent in justifications to questions in the Endorsement and Generation Tasks. Furthermore, except for some children in Grade 2, statistical concepts were used fairly consistently. This level of consistency should have been maintained or increased for the Endorsement and Generation Tasks because most traits included in the interview are somewhat variable within populations.

The Endorsement Task

In evaluating each of the seven explanations, participants had five response options available: very silly, pretty silly, not silly and not good, pretty good, and very good (see Appendix A: items 7, 8, and 9). As noted previously, endorsement was defined as choosing either a pretty good or a very good rating. Two aspects of endorsement were measured: (a) the number of explanations endorsed, and (b) the type of explanations endorsed. Of interest was whether there were age-related differences, as well as entity-related differences, in the number and types of explanations endorsed.

Number of Explanations Endorsed

To determine whether there were age and entity effects on the number of explanations endorsed, a 4(Age Group) X 3(Entity) analysis of variance was conducted with repeated measures on the last variable. Contrasts among means were conducted using planned tests for simple effects, with $\alpha = .01$ to help protect against Type I error.

Figure 7 shows the mean number of explanations for each grade and entity. Across the three entities, the mean number of explanations endorsed decreased with age $F(3,124) = 4.33$, $p < .01$. The average number of explanations endorsed per entity was greater for children in Grades 2 ($M = 2.53$, $SD = 1.58$) and 4 ($M = 2.19$, $SD = .79$) than for children in Grade 6 ($M = 1.67$, $SD = .77$) and adults ($M = 1.62$, $SD = .59$) ($p < .001$). Age effects on the number of explanations endorsed varied with entity, however, $F(6, 248) = 2.47$, ($p < .05$).

As shown in Figure 7, significant age effects on the number of explanations endorsed were limited to the biological entities, namely the puppy, $F(3, 124) = 5.40$ ($p < .001$) and the flower, $F(3, 124) = 4.33$ ($p < .005$). Compared to participants in Grade 6 and university, participants in Grades 2 and 4 considered more explanations to be reasonable for both the puppy ($p < .001$) and the flower ($p < .001$). Children in the younger grades have less opportunity to learn formally and informally about science than children in Grade 6 and adults (Korpan, Bisanz, Boehme, & Lynch, 1997). Consequently, they would likely have less specific knowledge about possible causes of animal and plant characteristics. Lack of specific knowledge about living things may have made younger children more hesitant than Grade 6 children and adults to rule out explanations.

For the pail, participants at all age groups endorsed approximately the same number of explanations (overall $M = 1.99$, $SD = 1.17$). The possible causes underlying color of an artifact are fairly obvious: If someone wants an artifact to be a certain color, they can make it a certain color by painting it or dying it. Participants in all age groups seem to be aware of these causes.

Types of Explanations Endorsed

Overview

The seven explanations investigated in the current study represent a range of ideas, some of which experts would consider to apply to (a) biological entities but not artifacts (e.g., genes), (b) artifacts but not biological entities (e.g., psychological factors such as wishes or intentions), (c) both biological entities and artifacts (e.g., environmental factors and perhaps God, if experts possessed this belief), and (d) neither biological entities nor artifacts, in the sense that the explanations are not scientifically sound (e.g., vitalism, preformation, fantasy). Age and entity effects on endorsement were investigated for each type of explanation. Also of interest was whether there were age related differences in the frequency with which individuals expressed patterns (a) - (d) across entities.

For each type of explanation, age effects on frequency of endorsement were investigated for each entity (puppy, flower, pail) separately. Using Pearson chi-square tests, age group (Grade 2, Grade 4, Grade 6, adult) was crossed with endorsement (Yes, No). When the chi-square test was found to be significant ($\alpha = .05$), further analyses were performed to establish which groups differed in endorsement frequency. Specific group comparisons (e.g., Grade 2 versus Grade 4) were also analyzed with Pearson chi-square tests. To reduce the probability of Type I error, the alpha level for the latter comparisons were set at .01.

Entity effects on frequency of endorsement were analyzed for each age group separately ($\alpha = .05$), using Cochran's Q tests for related samples. When entity was found to affect endorsement frequency, further analyses were conducted between specific pairs of entities (e.g., puppy versus flower), also using Cochran's Q tests for related samples (α = .01). Again, this conservative level was adopted for comparisons to reduce the probability of Type I error.

To determine whether pattern of endorsement across entities was affected by age, each pattern was analyzed using Pearson chi-square tests (α = .05). Number of participants who demonstrated each pattern (e.g., Endorse for all entities?: Yes, No) was crossed with age group. When significant effects were found, further Pearson chi-squares (α = .01) were used to determine which age groups differed. It should be noted that these patterns are not of equal importance for all seven explanations. Only those patterns that illuminate participant's evaluations are discussed, but all patterns are presented in Table 2.

When interpreting age and entity effects on frequency of endorsement, examples of justifications are discussed only when they help explain the patterns of endorsement. Focus is on justifications that were most frequently generated. Also, mean ratings data, which provides additional evidence concerning the effect of age and entity on ratings, are presented in Appendix B.

Genetic Mechanism

Although the term "gene" is not used in any of the genetic prompts, the term "things" refers to genes when presented in the context of the animal and plant (see items 7f, 8f in Appendix A). Experts would likely endorse this explanation for the biological entities. In the context of the pail, however, the term "things" is somewhat ambiguous. (see item 9f in Appendix A). If experts, interpreted "things" to mean genes for the pail, they would consider it nonsensical and therefore reject this explanation.

Figure 8 shows the percentage of participants in each age group who endorsed the genetic mechanism as a function of entity. Frequency of endorsement of the genetic explanation changed across age group, whether this explanation was considered in the context of the puppy, χ^2 (3, N=128) = 24.80, $p < .001$, the flower, χ^2 (3, N=128) = 46.77, $p < .001$, or pail, χ^2 (3, N=128) = 8.08, $p < .05$. For puppy, the genetic explanation was endorsed by more adults than children in Grades 2, 4, and 6 ($p < .001$), and the term "gene" was included in more justifications of adults than children. Genes were mentioned by two children in Grade 4 (e.g., "Parents pass things on, and these things are genes" S44), four children in Grade 6, and 29 adults. Of the remaining children who endorsed this explanation, approximately 50% in each grade assumed "things" referred to something biological (e.g., "They pass cells that do that." S78: Grade 6), or traits (e.g., "You get tiny things from your parents–nose, hair color..." S51: Grade 4). Children who did not endorse this explanation generally said parents do not pass on things to their offspring (e.g., "Parents can't put tiny things in a puppy" S18: Grade 2) or said that parents do not pass on instructions (e.g., "Mom can't make instructions to be brown." S54: Grade 4).

For flower, an age trend similar to that of the puppy emerged: More adults endorsed the genetic mechanism than children in all three age groups, ($p < .001$). Children in Grades 2, 4, and 6 were generally hesitant to endorse this explanation. The reasons given for their hesitancy were similar among these children. Of those children who did not endorse this explanation, the majority of children (average proportion = 67%) did not think that flowers have parents (e.g., "The flower can't get instructions from its parents because it has no parents." S85: Grade 6). For another 14% of children, and both of the adults who did not endorse this explanation, the idea that instructions are passed from one flower to another did not sound plausible (e.g., "Instructions can't be passed down in flowers." S108: Adult).

Finally, for pail, all age groups tended not to endorse the genetic explanation. Participants at all age groups gave similar reasons, including the fact that pails are not alive and that they attain their color through human intervention (e.g., "Pails are made white and painted red. They're not alive." S40: Grade 4). The few children who endorsed the genetic explanation mistook the "things" to mean paint or rust. Due to this misunderstanding, children endorsed this explanation more often than adults, although this difference did not reach significance at $\alpha = .01$.

Entity type had no effect on frequency of endorsement for children in Grades 2 and 4, although there was a trend toward endorsing the genetic explanation more often for the puppy than for the other two entities (see Figure 8). For children in Grade 6, endorsement frequency was affected by entity, $Q\ (2) = 22.30$ ($p < .001$) in that they endorsed the genetic explanation rating more often for the puppy than the flower, $Q\ (1) = 9.30$ ($p < .005$), and more often for the puppy than the pail $Q\ (1) = 15.21$ ($p < .001$). Generally, this pattern is similar to that seen in Grades 2 and 4. Children in all grades found the genetic explanation equally unacceptable for the flower and the pail. As seen in Table 2, very few children responded to entity type as an expert would. Only 13% of all children endorsed the genetic explanation for both the puppy and the flower, and not for the pail. Furthermore, 35% of all children never endorsed the genetic explanation either because they were uncertain of what "things" referred to, or because they said that the idea of "things" was silly.

Entity did affect adult's endorsements of the genetic explanation, Q (2) = 60.07 ($p < .001$), and the pattern of endorsements matched the pattern hypothesized for experts. As seen in Table 2, 94% of adults found the genetic explanation appropriate for both biological entities, but not for the pail. This proportion is significantly higher than seen for children, $\chi^2(1, N=128) = 81.46$, $p < .001$. Also, none of the adults rejected the genetic explanation completely. Thus, when evaluating the appropriateness of the genetic explanation, the distinction between biological entities and artifacts seems to develop and is quite clear by adulthood.

In summary, children who endorsed this explanation tended to do so mostly for the puppy. Children seemed hesitant to endorse the genetic mechanism as an explanation for color in flowers. In fact, their endorsements of the genetic mechanism for the flower was comparable to their endorsements of this explanation for the pail. Justifications were useful in determining why this result occurred. It did not appear that young children mis-categorized the puppy and flower with the pail. That is, there was no blurring of the biological-artifact line. Rather young children appeared to lack specific biological knowledge about plant reproduction, and, as found in Springer and Keils' study (1991), younger children had some problems with the idea that little things contain instructions. Adults tended to evaluate the genetic explanation in the way that an expert might: They endorsed this explanation for both biological entities, but not the pail. They had sufficient technical knowledge that enabled them to demonstrate this pattern.

Environmental Mechanism

Experts are currently of the opinion that although genes are partially responsible for color transmission between parent and offspring, the environment may affect the manner in which the genetic code for color is expressed. Thus genes alone, and environment alone, are not sufficient causes of color in living things. The environment may or may not be responsible for color in artifacts such as pail (e.g., rust, paint spill); color of artifacts is usually the result of human intention and action. Because of the qualified nature of this mechanism for both biological and non-biological entities (see items 7d, 8d, 9d in Appendix A), it is not clear whether experts' endorsements would be affected by the biological versus artificial aspects of the entities.

As seen in Figure 9, endorsement frequency did not vary with age for biological entities. For the puppy, the environmental explanation was endorsed by 34% of all participants. The primary reason for this relatively low level of endorsement is that many participants simply said that the environment does not affect color of things (e.g., "Lots of physical characteristics are not influenced by the environment." S104: adult). Also mentioned by participants in all age-groups was that fact that environmental effects are not likely to be permanent. For example, in the context of the dog, one child in Grade 4 said, "That's sort of silly because stain or paint would come off." (S33). Those who did endorse this explanation gave examples of things that could affect color (e.g., sun). Endorsement for flower was similar to endorsement for puppy. Thirty-five percent of all participants endorsed the environmental explanation for the flower. Furthermore, justifications were similar to those given for the puppy.

For the pail, there was an effect of age, χ^2 (3, N=128) = 20.89, p < .001. More adults than children endorsed the environmental explanation for color of this artifact (p < .001). Adults gave examples of things in the environment that could affect the color of a pail (e.g., sun, dye, rust from moisture, paint). Children who endorsed the environmental explanation for the pail mentioned similar examples. Most children, however, said that color of a pail is fixed and not likely to change simply though exposure to the environment (e.g., "Nothing around it can pick its color and it can't get color from anything around it." S87: Grade 6).

For children in all grades, entity had no affect on frequency of endorsement. A moderate proportion of children in each grade endorsed this explanation, regardless of entity. As seen in Table 2, children's endorsements did not appear to be affected by the biological-artificial dimension. Forty-five percent of the children's (n = 43) endorsements did not change with entity, with 33 of these 43 children rejecting the environmental explanation for all three entities.

Unlike children, adults' endorsements were affected by entity, Q(2) = 25.9 (p < .001). They were more likely to endorse the environmental explanation for the pail than for the puppy (p < .001) and for the flower (p < .001). Justifications helped reveal that children often took the prompt in its literal sense ("natural" environment causing a change in color), whereas many adults were willing to interpret it as including unnatural causes (paint) and human intervention. Trends revealed in Table 2 provide more evidence that adults had a tendency to endorse this explanation for the pail only (p < .001).

In summary, children and adults were comparable in the frequency with which they endorsed the environmental explanation for both biological entities. Both groups seemed to agree that for some traits, such as color, biological entities are generally fixed. Of course, some natural changes in color can occur as a result of prolonged exposure to the environment, but short-term transformations usually require exposure to unnatural things (e.g., paint) in the environment. Thus, it is not surprising that participants were slightly hesitant to endorse this mechanism for the puppy and flower. The children in Springer and Keil's (1991) study preferred the environmental explanation to other types of explanations, but those children were generally younger than children in the current study. Perhaps, less experience in observing the extent of environmental influence on biological traits made them more inclined to accept the idea that the environment can change biologically-based traits.

For the pail, more adults than children endorsed this explanation. That is, when crossing the biological-artificial boundary, frequency of endorsement did not change for children. For many adults, frequency of endorsement did change, with adults generally finding this explanation more appropriate for the pail.

Psychological Mechanisms

Experts would agree that intentional forces have no effect on color transmission between parent and offspring and thus would not likely endorse this explanation for the puppy or flower (see items 7c, 8c in Appendix A). Intentions can indirectly cause color in artifacts through some sort of action, (e.g., If you want a red pail, you can paint it red), but experts' endorsements would depend on whether the prompt for the pail was taken literally, such as in the case of magical thinking, or if it was interpreted to imply human action (see item 9c in Appendix A).

As seen in Figure 10, there were no age effects on frequency of endorsement, regardless of entity. For the puppy, 97% of all participants said that intentions could not affect its color (e.g., "You can't change color. If its going to be brown, its going to be brown. It doesn't matter what the owner wants." S1: Grade 2). Of those who endorsed this explanation for the puppy, only one child in Grade 2 said it was possible to change color of a puppy through wishes. The remainder gave justifications that indicated that they actually did not think wishes could change color directly, but mentioned some other intermediary cause (e.g., "Maybe if they wanted it to be brown, God would make it that way....No, just saying I want a brown puppy will not make it brown." S19: Grade 2). Similarly, for the flower, 93% of participants did not endorse the psychological mechanism for this entity, again stating that wishes cannot change color of flowers (e.g., "People have no say in a flower's color." S127: Adult). Those who did endorse the psychological explanation for the flower again mentioned some other intermediary cause (e.g., "He liked the color and so picked that color." S15: Grade 2). Thus, all age groups recognized the inappropriateness of the psychological mechanism for explaining color in living things. For the pail, however, most participants (overall proportion = 89%) said that wishes could cause it to be a certain color, but further implied that actions must be taken to color the pail (e.g., "People making the pail can choose its color." S75:Grade 6).

Entity type affected endorsement of the psychological explanation for participants in Grade 2, $Q(2) = 36.21$ ($p < .001$), Grade 4, $Q(2) = 43.10$ ($p < .001$), Grade 6, $Q(2) = 54.07$ ($p < .001$) and university, $Q(2) = 60.07$ ($p < .001$) (see Figure 10). Within each age group, the number who endorsed this explanation for color of the pail was higher than the number who endorsed this explanation for the biological entities. Pattern of endorsement across entities was not identical across age groups, however. As seen in Table 2, most participants in Grades 4, 6, and university (overall proportion = 87%) endorsed the psychological explanation for the artifact but for neither biological entities. Fewer children in Grade 2 (59%) demonstrated this type of distinction between biological and artificial entities, χ^2 (1, N=128) = 10.88 ($p < .001$). Although children in Grade 2 seem to appreciate the inappropriateness of the psychological explanation for the biological entities and appropriateness of this explanation for artifacts, a clearer distinction between biological and artificial entities develops with age for some children.

In review, regardless of age, participants tended to find the psychological explanation inappropriate for both biological entities but appropriate for the pail. There are slight developmental changes in the frequency with which this pattern is seen, but many children as young as Grade 2 perform as adults in distinguishing the appropriateness of the psychological explanation for artifacts as opposed to biological entities. This finding is consistent with those found by Springer et al. (1991). When children are directly asked to evaluate this mechanism in the context of biological entities, they tend to find it silly but in the context of artifacts, tend to find it appropriate. They generally distinguish situations to which psychological mechanisms do and do not apply.

Theological (God)

It is not possible to predict how experts would evaluate these explanations (see items 7g, 8g, 9g). Although God, as a divine being who chooses color (i.e., theological explanation), is not scientific in the sense of being falsifiable, many scientists have faith in the divine. For such individuals, it is unlikely that their religious beliefs would extend to explaining traits of artifacts, however, except perhaps indirectly through human intervention.

As seen in Figure 11, frequency of endorsement of the theological explanation changed with age, for the puppy, χ^2 (3, N=128) = 33.87, $p < .001$, the flower, χ^2 (3, N=128) = 33.44, $p < .001$, and the pail, χ^2 (3, N=128) = 16.16, $p < .001$. For the biological entities, age trends were fairly similar. More children than adults endorsed this explanation for the puppy ($p < .001$) and the flower ($p < .001$). It could be inferred from their responses that these children believed in the existence of God. Seventy-five percent of children said that God can choose color (e.g., "God makes puppies...he can choose color." S6: Grade 2). Of the children who did not endorse this explanation, one third were not sure if God would directly affect the color of individual entities. Most of the remaining two thirds said that God probably could affect color, but is too busy to be involved in particular animals and plants (e.g., "God doesn't pick the color of every puppy." "There are too many flowers...it would take too much of his time to pick all their colors." S68: Grade 6). Only three children said that God could not affect the color of these entities.

Children in grade 4 endorsed this explanation at a higher frequency than the other two groups of children for both the puppy ($p < .005$), and the flower, ($p < .005$), although it is not clear why this pattern emerged. Endorsement of the idea that God could affect the color of a pail decreased with age, but the only significant age differences were between adults and children in Grades 2 ($p < .001$) and Grade 4 ($p < .005$).

A minority of adults found the theological explanation to be acceptable. Of those who did, all said that God can choose color of things. Only one adult incorporated both God and genes in their explanation, by stating that "God could be responsible for genes." (S118: Adult). Of the adults who did not endorse this explanation, 54% stated that they did not believe in God. Another 46% of adults said that genes, not God, determines color, or said that God is not involved in details such as the color of a puppy.

Entity affected the rate of endorsement for all three groups of children. Endorsement of the theological explanation for the puppy was comparable to the flower. Furthermore, the idea that God could choose color was endorsed more frequently for the biological entities than the pail (for puppy-pail and flower-pail comparisons, all $p < .01$). Children generally said that God can do anything, but only for living things (e.g., "God can't choose the color for unliving things." S7: Grade 2). Some children also mentioned that because people make pails, they choose the color, not God. For adults, endorsement frequencies differed for the puppy versus pail comparison ($p < .01$). The flower versus pail comparison was not significant at $\alpha = .01$, ($p < .05$), although it should be noted that floor effects may have affected this analysis.

As seen in Table 2, the pattern of endorsement across entities varied with age. Children in Grade 2 and 4 were more likely than the other groups to endorse the idea that God can choose color of all three entities ($p < .01$), while adults were most likely to not endorse this explanation for any of the entities ($p < .001$). Endorsements of children in Grade 4 were more affected by the biological-artificial dimension than the other age groups, in the sense that many said that the theological explanation was appropriate for color of biological entities, but not the pail ($p < .001$). Children in Grade 6 were distributed fairly equally across the three patterns outlined above. To some extent, participants in this study seemed to follow the following developmental pattern: (a) endorse the idea that God could choose color of all entities, (b) endorse this idea for biological entities only, (c) reject the idea that God would choose color, regardless of entity type.

In summary, compared to adults, children expressed more acceptance of the idea that God can influence color of things, but more so for living things than artifacts. The tendency to reject this explanation increased with age.

Preformation

This is an non-mechanistic explanation that might be used by individuals who do not realize that color results from some sort of causal event. Although this view held a prominent position among seventeenth and eighteenth century biologists (Mayr, 1982, cited in Springer & Keil, 1991), biologists today construe color of various species to result from genetic causes which can be moderated by environmental factors, and they recognize that color is not typically expressed at the initial stages of development. Thus, it is expected that experts would reject the preformationist idea for biological entities (see items 7a, 8a in Appendix A). Preformation does not make sense for artifacts, and therefore experts would also likely reject this explanation for the pail (see item 9a in Appendix A).

Figure 12 shows the percentage of participants who endorsed the preformationist mechanism for color as a function of entity. Age effects on frequency of endorsement were restricted to the puppy, χ^2 (3, N=128) = 27.74, $p < .001$ and the flower χ^2 (3, N=128) = 22.67, $p < .001$. For the puppy, more children than adults found the mechanism to be acceptable ($p < .001$). Although 52% of the children endorsed the explanation, none actually said that puppies are preformed, however. Rather, they generally believed that puppies attain their color before birth (e.g., "It came out brown because it was brown while still inside." S69: Grade 6). Of the children who did not endorse this explanation, the majority said that color changes after birth (e.g., "Puppies aren't their actual color when they're born, it changes when they get older." S33: Grade 4). The remainder were uncertain of the validity of this explanation. Only one adult endorsed this idea as an explanation for color in the puppy, but it is not clear if she supported the idea of preformationism or predetermination (e.g., "the puppy is developed right from the beginning...it's planned from the start." S108: Adult)

For the flower, the rate of endorsement steadily decreased with age. A few participants in Grades 2, 4, and 6 indicated that flowers are preformed inside the seed (e.g., "If you looked inside the seed, you would see a pink flower." S63: Grade 4), and the remainder who endorsed this idea said that flowers attain their color before they bloom (e.g., "If you look inside the seed, you would see a pink dot, not a flower." S59: Grade 4). The majority of participants in Grade 6 and university did not endorse this explanation, and of these individuals, 58% said that flowers are not preformed (e.g., "You wouldn't see a pink flower inside the seed." S82: Grade 6). Another 16% had problems accepting the idea that color is present in flowers before blooming (e.g., "Flowers don't get their color when still growing...it would be green before it blooms." S92: Grade 6).

For the pail, age groups did not significantly differ in their endorsements, but lack of age effects may be due to floor effects. Relatively few participants actually said that pails are preformed. Of those who endorsed this explanation for the pail, 62% were not sure why they said it was a good idea. The remainder of participants who endorsed this idea said that the pieces that make up the pail could be red (e.g., "The stuff they make it out of could be red." S35: Grade 4) . Participants who did not endorse this explanation either indicated that the prompt did not make sense (e.g., "That doesn't make sense–how can metal that makes up the pail not be seen?" S102: Adult) or said that components of pails are colorless before assembly ("There can't be tiny red pieces before its painted...you need to build the bucket first and then paint it." S96: Grade6).

Entity had similar effects on endorsement frequency for children in Grade 2, $\underline{Q}(2) = 14.95$, $\underline{p} < .001$, and Grade 4, $\underline{Q}(2) = 9.882$ (see Figure 12). These children generally found preformationism more acceptable for both biological entities than the pail (all $\underline{p}$s < .01). Children in Grade 6 were more willing to endorse this idea for the puppy than the pail, but endorsed the flower and pail at comparable frequencies. Shown in Table 2 is confirmation that, compared to children in Grade 6, more participants in Grades 2 and 4 endorsed preformationism for both biological entities

Also seen in Table 2 is the increased tendency with which preformationism was rejected completely across age, χ^2 (3, $\underline{N}$=128) = 37.68, $\underline{p} < .001$. Children in Grade 2 were more hesitant to reject preformationism outright that children in Grades 4 and 6 ($\underline{p} < .01$), who in turn were more hesitant to reject this idea totally than adults ($\underline{p} < .001$). Adults rarely endorsed preformationism for any entity.

In review, all groups tended to reject preformationism for the pail. Young children were more willing than older participants to endorse preformationism for both biological entities and adults infrequently endorsed this idea. In their justifications, the majority of children revealed that they do not think that animals are preformed, but that color is present before birth. Springer and Keil's (1991) also included preformationism in their task to provide children who lacked a causal mechanism a default response. In the current study, where participants were asked to rate each explanation independently of one another, children were comfortable holding on to this view along with other causal explanations. For example, the idea of preformation, when not taken literally, but instead taken as version of predeterminism (e.g., It was planned to be pink) is consistent with the genetic explanation. Almost all adults interpreted the preformationist idea in the literal sense of the word (e.g., the idea that flowers are fully formed while still inside the seed) and therefore were more willing than children to reject the notion.

Vitalism

Expressed in the prompts are the ideas that structures of biological entities have intentions, which is a vitalistic notion, and the idea that artifacts are living entities, which is an animistic notion (see items 7e, 8e, and 9e in Appendix A). Although the science of some cultures (e.g., Japan) was at one time vitalistic rather than biologically based, such ideas are no longer endorsed in the scientific community. Neither is the idea of animism. Thus, these ideas would likely be rejected by experts.

As can be seen in Figure 13, vitalism is never endorsed beyond Grade 4, and is endorsed by only a minority of children in Grade 2 and 4. Except for one child in Grade 2, those who accepted vitalism did so only for the biological entities, making claims such as "Skin can think" (S13: Grade 2) and that "Flowers are alive and can pick their color" (S43:

Grade 4). Among those who rejected this idea for the puppy and the flower, all said that it was not possible for skin or flowers to think. Response patterns across entities are evident in Table 2. A little over half of children in Grade 2 completely rejected the idea of vitalism. The tendency to reject vitalism altogether increased significantly across age groups, χ^2 (3, N=128) = 30.74, $p < .001$, especially between Grades 2 and 4 ($p < .001$).

Fantasy

Beyond early childhood, most individuals consider fairies to be fictional characters. Therefore, it is highly likely that any expert would reject this mechanism as an explanation for color for all three entities (see items 7b, 8b, and 9b in Appendix A).

As shown in Figure 14, no one beyond Grade 2 endorsed this explanation. All of those who rejected the idea simply said that fairies do not exist (e.g., "There are no fairies." S96: Grade 6). Eight children in Grade 2 accepted the notion of fairies, half endorsing the idea that they can influence color for all three entities (e.g., "Fairies are real and can do that." S3: Grade2). The remainder of these eight children tended to endorse the idea only for biological entities. Rate of endorsement was too low to reveal any entity effects. This low rate of endorsement is consistent with other investigators of children's beliefs that fairies can intervene (e.g., Springer & Keil, 1991).

Explanation Preferences: A Brief Review

Endorsement of explanations, such as those outlined above, varied within age groups, but preferences emerged as well. In this section, an explanation is said to be preferred by a group if it is endorsed by the majority of individuals in that group. As shown in Figures 15 to 17, some preferences changed to a small degree across age groups, while others changed to a greater degree. Order of discussion is from most preferred explanation to least preferred explanation.

For the puppy, the idea that God chose its color was the only explanation endorsed by the majority of children in all three grades (see Figure 15). That so many children accepted this explanation is not surprising, considering that these children were being educated at a Catholic school. Children revealed preferences for only a few other explanations. Sixty-six percent of children in Grade 2 regarded the idea of preformation as being appropriate, but focused on the idea that color is predetermined or evident at inception, rather than the idea that puppies come into existence fully formed. This notion was also endorsed by just under half of the children in Grades 4 and 6. The genetic explanation was endorsed by the majority of the children in Grade 6. Generally, these children agreed that parents pass things onto their offspring and that these things affect color. Few children included the word "gene" in their justifications. Within each grade, none of the other explanations were endorsed by the majority of children; the environmental explanation was accepted by a moderate proportion of children and the ideas of vitalism, fantasy, and psychological causes were found unacceptable by most children. For adults, only the genetic explanation was preferred. The idea that the environment could affect color of the puppy or that God chose the color of the puppy was found acceptable by a moderate proportion of adults. Similar to children, adults found the ideas of vitalism, fantasy and psychological causes to be inappropriate explanations for color of the puppy, but unlike children, they rejected preformationism.

When Figures 15 and 16 are compared, it can be seen that *relative* levels of endorsement for each age group did not change radically when participants were asked to rate the explanations in the context of the plant. Notable exceptions include a decrease in the extent to which children endorsed the genetic explanation. Recall that the children who found the genetic explanation problematic did so primarily because they said that plants do not have parents. The idea that plants could receive instructions of any sort was also considered unlikely by a few children and by both of the adults who rejected this idea for plants. Also notable is the fact that children in Grade 6 did not show any strong preferences for any of the proposed mechanisms. All explanations were endorsed by less than 50% of children in this grade. It is not clear why this general decrease occurred and why it was restricted to children in Grade 6.

Finally, an overwhelming majority of participants across all age groups considered the Psychological explanation to be acceptable for color of the pail (see Figure 17). All of these individuals stipulated that color of an artifact is determined by human wishes, but further added that human action (i.e., painting the pail) is also necessary. Most adults also believed that the environment can affect the color of artifacts. Unlike adults, a moderate proportion of children endorsed the environmental explanation and the idea that God chose the color of the pail, but generally concurred with adults regarding the inappropriateness of preformation, vitalism, fantasy, and genetics as explanations for color of an artifact.

<u>Predictions for the Generation Task</u>

Responses in items 7 through 12 revealed much about how individuals construe issues relevant to inheritance and how their thoughts about inheritance are influenced by age and entity. Based on this information, the following section includes some speculations about how individuals would answer the series of open-ended questions thematically focused on inheritance, as they were in the Generation Task. The order of the predictions are based on the order of explanations presented in the Endorsement Task. Expression of statistical concepts was also of interest and is discussed last.

It was evident in their responses that most adults possessed considerable knowledge about genetic mechanisms underlying inheritance of traits. Therefore, it would be reasonable to expect that most adults should spontaneously generate genetic responses and should consistently generate this type of response for most, if not all, questions. It should be noted, however, that even though all adults demonstrated much knowledge when directly asked about genes in item 12 (i.e., Background Knowledge-Concept of Genes), three adults did not include the word "gene" in their justifications to items 7b and 8b. Thus, if some adults do not provide genetically-based responses, even when prompted to do so, then some might not spontaneously provide this type of response. Conversational rules regarding redundancy sometimes dictate how people respond to a series of questions on a related topic (e.g., Schwarz, 1995).

Knowledge about genes remained inert for most children, despite cuing. In item 12, one child in Grade 2, 13 children in Grade 4, and 16 children in Grade 6 demonstrated knowledge about genes. In items 7b and 8b, genes were referred to by only three children in Grade 4 and five children in Grade 6. Therefore, it would be justifiable to expect that only a few children might spontaneously use their knowledge about genes when generating their responses. Many children did mention the fact that parents pass things onto their offspring and many also stated that these things influence traits of the offspring. Therefore, these ideas would be expected to emerge in their answers.

Children and adults were somewhat comparable in their responses to the environmental prompts in items 7d and 8d, and to questions concerning the variable trait (height) examined in item 11. Many of the items in the Generation Task involve biological beings and traits that vary within populations and within one's lifetime. Therefore, it would be expected children and adults would be comparable in terms of frequency with which they invoked the environment as an explanation. Because the proportion of individuals who endorsed the environmental explanation for color of living things was somewhat moderate, this idea would not likely have been expressed with much frequency or consistency.

Except for one child in Grade 2, there was no indication that individuals construed inheritance of color in terms of psychological mechanisms. Even children as young as 6 years of age deemed intentional mechanisms to be inappropriate explanations for color in biological entities. Given these trends, none of the individuals in any of the age groups were expected to generate this type of explanation in their responses to questions in the Generation Task.

Most children endorsed the theological explanation, and did so more frequently than adults. Furthermore, these children received weekly instruction in Christian theology. It should be expected that more children than adults would generate this type of reason when presented with a series of questions on inheritance, and do so more consistently. Children in Grade 4 especially endorsed this mechanism. Hence, it would be probable that these children would have used this type of explanation most frequently when generating their answers.

Few preformationist ideas were included in children's justifications, and adults generally rejected this idea. Therefore it is unlikely that these ideas would be found in participants' answers. The idea that some traits are established before birth was frequently expressed, however. Therefore, it is reasonable to expect that this type of thinking would have appeared in the form of statements such as "They were born that way." Vitalism was also rejected by most individuals, except for a few children in Grades 2 and 4, and fantasy was endorsed by only a few children in Grade 2. Therefore, explanations involving vitalism and/or fantasy would be unexpected.

Because of the open-ended nature of the Generation Task, participants may generate a variety of explanations, not just the ideas assessed in the Endorsement Task. For example, statistical concepts were used consistently in item 11 (see Appendix A). Therefore, statistical responses would be expected in the Generation Task.
Other types of explanations were also anticipated as well, but hard to predict based on the Background Knowledge and Endorsement Tasks.

The Generation Task

In the following section, responses to 15 non-cued, and open-ended questions in items 1 to 9 are discussed (marked with asterisk in Appendix A). For the sake of comparability, questions that were contingent on participants' responses, and consequently presented to only a subset of all participants, were not included in the analysis (e.g., item 4: "Why won't the baby be very short like her parents?" was presented only to participants who did not chose the option "very short" when answering the previous question).

With exception of the open-ended question in item 9 (i.e., color of pail), participants conceivably could have invoked their knowledge about biological inheritance when answering all questions. They generated various types of responses, however, which in turn were categorized according to whether they (a) were congruous with current biological theory of inheritance and with a clear causal mechanism (e.g., genes, environment, physiological mechanisms), (b) were congruous with biological theory of inheritance but with a mechanism that is not clear (e.g., a biological relationship to ones' kin or species), (c) were psychological or behavioral, (d) reflected theological beliefs (e.g., God), and (e) were non-causal (e.g., reference to statistical averages and variation, use of anecdotes). Ideas such as vitalism, preformation, and fantasy were also of interest. These types of responses were never generated, however, and are not discussed further in this section.

The question that is the focus of this section is: How does generation of explanations change with age? Two aspects of generation were evaluated across age: (a) the number of explanations generated, and (b) the types of explanations generated.

Number of Explanations Generated

To determine the effects of age on the number of different explanations generated in the interview, the ideas expressed in each response were coded. Codes were then tabulated across questions and analyzed with a one way analysis of variance ($\alpha = .05$), with age as the independent factor. Participants generated a variety of explanations across the interview; between three and 12 different types of ideas were expressed. Age groups did not differ in the mean number of different explanations generated. The number generated in each age group was as follows: Grade 2: $M = 6.84$ ($SD = 2.00$, range = 3 to 12 explanations); Grade 4: M = 6.81 (SD = 1.40, range = 3 to 9 explanations); Grade 6: M = 6.84 (SD = 1.56, range = 3 to 10 explanations); adult: M = 6.15 (SD = 1.37, range = 3 to 9 explanations). Thus, all age groups had a variety of ideas available to them when answering the series of questions about inheritance. There was some variability in regard to the types of ideas emphasized by different age groups, however.

Types of Explanations Generated

Assessment of age effects on type of explanations generated was achieved by analyzing each type of explanation separately and asking about: (a) *frequency of use*–the number of participants in each age group who generated this type of explanation at least once in the interview across the various questions, and (b) *consistency of use*–the number of questions in which participants in each age group generated each type of explanation. That is, did they generate the explanation for all 15 questions, or only a subset?

Frequency of use was analyzed using Pearson Chi Square tests ($\alpha = .05$) with age group (Grades 2, 4, 6, and adults) crossed with generation of explanation (i.e., Was this explanation generated at least once in the interview? Yes or No). When the chi-square test was found to be significant, further analyses were performed to establish which groups differed in endorsement frequency. Specific group comparisons (e.g., Grade 2 versus Grade 4) were also analyzed with Pearson chi-square tests. To reduce the probability of Type I error, the alpha level for each comparison was set at .01.

Consistency of use was analyzed by tabulating the number of times the explanation of interest was used across the selected questions (maximum = 14 or 15, depending on whether the explanation was appropriate for item 9–color of pail) and conducting a one way analysis of variance, with age as the independent factor ($\alpha = .05$). Contrasts among group means were conducted using planned tests for simple effects, with $\alpha = .01$ to help protect against Type I error. Because the concept of consistency does not make sense when applied to participants who never generated the explanation of interest (e.g., Genetic explanation), only those individuals who generated the explanation at least once in the interview were included in the consistency analysis. Summary tables of frequency and consistency are presented in Tables 3 and 4. Each of the categories and sub-categories presented in the tables will be discussed in order. Frequency of use is discussed first, followed by consistency. When item-related effects clarify consistency, they are included in the discussion. Finally, an overview is provided of the proportion with which each category of response was generated by each age group.

Explanations Congruent with Scientific Theories and with a Clear Mechanism

Genetic Explanations. As seen in Table 3, there was an age effect on the frequency with which participants generated a genetic response, χ^2 (3, N=128) = 74.17 p <.001. Not surprisingly, more adults than children included genes in their responses (p <.001). All adults, but only a minority of children, generated this idea. The single child in Grade 2 who demonstrated knowledge about genetics in item 12 (see Appendix A: Background Knowledge on Genetics) generated a genetic answer in the Generation Task. Only 46% of children in Grade 4 and 63% of children in Grade 6 who had this knowledge used it in the Generation Task, however. In other words, although a number of children possessed the knowledge they needed to answer a question on inheritance by using the concept of genes, they did not use it, even when given repeated opportunities to do so.

Table 4 shows the consistency with which various types of explanations were generated in the interview. Consistency with which genetic ideas were generated varied as a function of age, $F(3,45) = 19.437$, $p < .001$. Adults were more consistent in their use of genetic ideas. Out of a possible 14 questions (genetic explanations do not apply to item 9: pail), adults generated a genetic explanation more times ($M = 10.4$ questions) than children, ($p < .0001$) (overall $M = 4.71$ questions, range = 1 to 9 questions).

Also shown in Table 4 is the fact that some adults were more consistent than others. Four adults referred to genes in 50% or fewer questions. Among the 28 adults who referred to genes in 51% or more questions, 4 generated this idea in 51% to 75% of the questions, 23 generated this idea in 76% to 96% of the questions, and one adult invoked the notion of genetics in response to all 14 questions. In light of the fact that all adults demonstrated considerable knowledge when directly asked about genes, and that none of the 14 questions precluded a genetic response, it is possible that conversational rules contributed to the level of consistency demonstrated. That is, some adults may have felt that once they demonstrated genetic knowledge in response to one question, mentioning genes in every single answer would seem repetitive.

Children who mentioned genes generally included this idea in less than half of their answers, with the exception of four children in Grade 6 (see Table 4: 51% + column). It is possible that their level of knowledge of genes prevented them from seeing the applicability of genetic explanations to all 14 of questions, or that they do see the applicability, but were responding in accordance with some conversational rule. It is not possible to determine which of these two hypothesis is more likely in the current study.

It should be noted that questions were somewhat variable in the extent to which they elicited genetic responses, and this may have affected consistency levels. Some questions may have caused participants to focus on other explanations, while others may have actually caused participants to recognize the relevance of genes to the scenario being depicted. Examples of the former included items in which participants were asked to reason about traits in animals that do not share kinship but share species-ship (see items 1c & 1d, 2c & 2d in Appendix A). In their explanations (in items 1d and 2d), genes were mentioned by only 28% and 13% of adults, respectively. Also, in the open-ended question whereby participants were asked to explain how a flower got its color (see item 8 in Appendix A), 63% of adults generated a genetic explanation. In fact, one adult said "Something biological, but not genes, caused the flower to be red." (S126). Children were affected in a similar manner. Of those who generated a genetic response at least once in the interview, none or only one child mentioned genes when answering these questions.

Other questions did not really affect generation of genetic explanations among adults; 75% or more adults mentioned genes in their answers to all other questions where genes applied. Children, however, were more likely to mention genes when responding to questions in items 3 and 4 than other questions. In item 3, participants were asked to compare the appearance of people to parents versus friends and parents versus grandparents. Similarly, in item 4, they were asked to compare one aspect of appearance of a child to its biological parents versus its adoptive parents. Of those who generated a genetic response at least once, 76% generated a genetic response when explaining why people look more like their parents than their friends, approximately 50% generated a genetic response when explaining why people look more like their parents than their grandparents, and 50% generated this response when comparing a child to its biological and adoptive parents. For the remaining questions, the minority of children gave genetic reasons. Thus, children need some encouragement to use their knowledge about genes, and asking them to make comparisons seems to be the key.

Genetic-related explanations. Responses that included ideas that are often integrated in scientific theories of genetics, but did not include the word "gene," despite additional probing, were coded as genetic-related. Examples of such concepts are inheritance, predetermination, and evolution. As can be seen in Table 3, 37 individuals, or 29% of all participants generated this type of response. There were no significant age effects on the frequency or consistency with which these explanations were generated.

Thirty-one participants (24%) incorporated the notion of inheritance of traits in their answers without also referring to genes. The were no age differences with regard to the frequency with which this idea was used, only the language varied. Adults tended to use more sophisticated language (e.g., "...it can be traced back to pollen and heredity." S109), whereas children used expressions such as "You look more like your parents because that's their baby and things get passed on." (S5: Grade 2). About 30% of the children and all adults actually used the term "gene" elsewhere in the interview. In other words, these individuals knew about genes, but chose to express the same idea in a different way. Again, this behavior may reflect a sort of conversational rule of avoiding redundancy. The concept of inheritance (without the term "genes") was used for only a few questions (M = 1.9 questions, range = 1 to 5 questions).

Six participants, three adults and three children, included in their responses, the notion of predetermination (e.g., "The flower turned out red because that's the color it's supposed to be.", S24: Grade 2). This idea was not used consistently (see Table 4). Rather, it tended to be generated in response to the open ended question in item 8: "Why do you think it is that this flower is pink instead of a different color? What do you think caused it to be pink?" (see Appendix A). All three children who generated predeterministic ideas lacked knowledge about genes, but their responses reflect their intuitions that some sorts of traits are established very early in development.

The concept of evolution was not expressed until the sixth grade and was rarely mentioned in the interview. An example of this response included "It's not the dog's puppy, but they're the same type of breed, so they evolved the same way." (S65: Grade 6). The infrequency with which this idea was generated may be due to the fact that the scenarios depicted in the interview involve inheritance of traits across a single generation, or don't cue participants to consider inheritance across more than one generation. All of individuals who incorporated evolution in their answers possessed knowledge about genes. No particular questions tended to elicit this type of response.

Physiological explanations. These mechanisms are non-genetic, but involve some sort of physiological transfer of traits. Some of these mechanisms are incorrect from a scientific point of view (e.g., "the baby would have blue hands when it's born...it would go through the mother's blood and into the baby." S5: Grade 2). Others were technically correct, but did not contain enough information to ascertain whether participants were actually referring to genes (e.g., "The parents pass on cells to the baby that make it have a large heart." S37: Grade 4). The frequency with which this idea was generated varied with age, χ^2 (3, N=128) = 16.63, $p < .001$. As seen in Table 3, fewer adults than children used these ideas in their answers, χ^2 (1, N=128) = 11.81, $p < .001$. The low frequency among adults presumably is due to the fact that they had at hand, knowledge that is technically more correct.

Although it appears in Table 4 that children generate this type of explanation more often than adults, the differences are not statistically significant. Participants gave a physiological answer an average of 1.77 times (range = 1 to 5 answers). The question that particularly elicited this type of response from children involved a trait that was in fact was not genetic, but acquired (see Appendix A, item 5). When asked whether a trait that was acquired by parents (i.e., hands that became dyed blue as a result of their job) would be passed on to the offspring before birth (i.e., What color of hands do you think the baby will have when it is born?), eight children said it would be passed on, and 21 said it might be possible for this trait to be passed on. Although seven of these children had knowledge about genes, none included genetic ideas in their justifications. Perhaps they were aware that genes play no role in acquired traits. They had to come up with some sort of explanation, however, and in this situation, physiological mechanisms were plausible.

Environmental explanations. As seen in Table 3, environmental explanations were generated by most participants in each age group. Ninety-one percent of participants provided an example or examples of environmental factors that may contribute to the traits investigated in the interview, including color of the pail. The lack of age differences seen in generation of environmental explanations matches the pattern seen in the Endorsement

Task, whereby all age groups were similar in the extent to which they endorsed the environmental explanations for a plant and animal. Also, participants in this study were in agreement with regard to how much the environment could affect a variable trait, such as height (see Appendix A: item 11).

As shown in Table 4, all groups were similar in the consistency with which they generated environmental explanations. Individuals who suggested environmental factors as a causal factor did so an average of 1.73 questions (range = 1 to 5 questions). Three items seemed to elicit this type of response more than others. In the context of the adoption scenario (see Appendix A: item 4), 57% of all individuals made references to environmental factors (e.g., "The baby will be very tall (like the adoptive parents) because they might give her food to grow tall like them." S43: Grade 4), although the tendency to generate environmental reasons in this question increased with age, χ^2 (3, N=73) = 16.42, $p < .001$. In the context of the acquired trait (see Appendix A: item 5), 45% of all individuals noted that such traits necessitate exposure to certain environmental factors (e.g., "The baby won't have blue hands unless it worked in paint factory." S3:Grade 2). Children were more likely to make this observation than adults ($p < .05$), perhaps because adults focused primarily on genetic reasons for why the trait would not be passed on. Finally, when asked what caused a flower to be pink instead of another color (see Appendix A: item 8) none of the adults, but 25% of the children, cited environmental causes (e.g., "The rain made it pink...chemicals in the rain can change the color of the flower." S84: Grade 6). Very few participants (between 1% and 9%) referred to the environment in other items.

Despite the fact that the environment plays a critical function in scientific theories of inheritance, participants did not place emphasis on this factor when explaining inheritance. Even university students, who presumably completed some biology courses in high school, placed relatively little emphasis on the environment when explaining traits. Perhaps this reflects the fact that for most biological traits, the environment is not depicted in the science classroom as being the ultimate cause, but is usually described as being an intermediary cause.

Explanations Congruent with Scientific Theories, but with Unclear Mechanism

Some ideas that were generated in the justifications seemed to imply concepts that are biological in nature, but lacked specific biological mechanisms. These ideas include the general concept of kinship, species-ship, growth, and birth.

Kinship. All participants mentioned kinship at least once in the interview, but as seen in Table 3, not all participants specified the biological mechanism by which kinship enables inheritance (e.g., "It will have very small ears because the mother has very small ears." S5: Grade 2). The frequency with which kinship was mentioned without further specification of biological mechanisms (i.e., kinship-alone) decreased with age, χ^2 (3, N=128) = 17.66, $p < .001$. Fewer adults than children generated this type of explanation ($p < .001$). That is, whenever adults mentioned kinship in their responses, they were more likely than children to elaborate on the nature of the biological mechanism underlying inheritance, usually in terms of genes. Also, as seen in Table 4, the consistency with which kinship-alone was generated varied with age, $F(3,112) = 70.24$, $p < .001$. Children (mean number of questions = 4.84) generated this type of explanation in response to more questions than adults ($p < .001$).

It should be pointed out that not all responses that incorporated the notion of kinship omitted a biological mechanism, but for young children, most did. There was an increasing trend across age groups to recognize the insufficiency of including kinship-alone when answering questions about inheritance, $F(3,126) = 90.90$, $p < .001$, especially between childhood and adulthood ($p < .01$). A biological mechanism was not included in an average of 71% , 62%, and 53% of all the kinship responses generated by children in Grades 2, 4, and 6, respectively. For adults, only 17% of the responses that included kinship failed to include a biological mechanism.

Most questions tended to elicit references to kin. Exceptions include the scenarios involving animals that share species-ship but not kinship (see Appendix A: items 1a and 2a unrelated infants). In these items, participants were explicitly told that the entities (i.e, dogs and horses) portrayed were not related, except through shared species-ship. Therefore, it was not surprising that most answers were phrased in terms of species-ship rather than kinship. When kinship was mentioned in response to the questions in items 1a (29% of all participants) and 2a (37% of all participants), participants were typically expressing the fact that lack of kinship makes it unlikely that the entities would share the unusual biological trait. Also, only 8% of all participants, mostly adults, mentioned kinship when asked how they said a flower got its color (see Appendix A, item 8). Only one child in Grade 2 spontaneous referred to parent plants in the open ended question. In fact, in the Endorsement Task, 47% of all children explicitly that flowers do not have parents.

Species-ship. As seen in Table 3, all age groups generated this type of idea with similar frequency (53% of all participants). Consistency was also similar across age groups (see Table 4). On average, species-ship was mentioned in response to 1.54 questions (SD = .85), and almost all instances were restricted to items 1 and 2 (see Appendix A). "Species" was explicitly referred to in these items by the phrase "this kind", and probably cued participants to consider species on these four questions. Participants placed less focus on specie-ship when kinship was mentioned.

When species were mentioned, participants rarely provided a biological mechanism whereby they could explain why members of a species would be more likely to share a trait with other members of their species than with members from different species (e.g., "It will have very small ears...I don't know anything about breeding–I have no other basis to go on." S105: Adult). Only 9% of responses that referred to species-ship were accompanied by an explanation of some sort (e.g., "Same type of dog...genetic makeup is similar so they will have similar characteristics." S106: Adult). In summary, when participants reason about inheritance, species-ship is either not a salient factor, or the manner in which species affects inheritance is not understood.

Growth. This idea is not typically incorporated in scientific explanations of inheritance, but was mentioned by 22% of all children (see Table 3). None of the adults generated this type of response in their justifications. As seen in Table 4, children generated this idea infrequently (e.g., He will grow up to have a big heart like his mother.) On average, growth was mentioned in response to 1.19 questions (range = 1 to 2 questions). Of the children who generated this idea, 90% lacked knowledge about genes. Furthermore, it is not clear from their explanations how growth results in particular traits. Children who generated this idea were never able to articulate how growth results in shared traits between individuals. They found it reasonable, however, to associate the biological processes of growth and inheritance.

Birth. As shown in Table 3, the frequency with which this idea was generated decreased with age, χ^2 (3, N = 128) = 44.41, $p < .001$. This explanation was used by more children than adults ($p < .001$). Seventy-five percent of all children mentioned birth at least once in the interview (e.g., "She was born to the short parents, so she'll be short" S10: Grade 2). Thus, most children viewed the parent-offspring relationship in terms of a biological link, not just a social one. Only 9% of adults referred to birth, but it is highly unlikely that most failed to mention this idea because they do not implicate birth in inheritance. Rather, it is likely that they recognize that reproduction enables genetic links to be formed and thereby explain their choices specifically in terms of genes rather than simply in terms of birth. About 39% of children who mentioned birth also referred to physiological mechanisms (e.g., shared blood). Another 23% knew what genes were, but only one child in Grade 4 articulated an association between reproduction and transmission of genes. The remaining half of children who mentioned birth seemed to possess some intuition as to its importance, but lacked an understanding of the biological links between this process and inheritance.

Overall, birth was not used with much consistency, but consistency varied with age, $F(3, 71) = 3.01$, $p < .05$ (see Table 4). Participants in Grades 2 and 4 mentioned this idea on more questions (average number of questions = 2.45) than participants in Grade 6 and adults (average number of questions = 1.31), $p < .01$. Two questions that were most likely to elicit this type of response involved scenarios that compared physical features of children to unrelated individuals (i.e., friends, adoptive parents) and related individuals (i.e., parents). Recall that a similar pattern was also seen in children's generation of genetic responses. Again, asking child to make comparisons such as these elicits responses that are biological in nature.

Psychological or Behavioral Mechanisms

It has been suggested by some researchers (e.g., Carey, 1985, 1991) that children do not construe biological phenomena such as inheritance within a biological framework, but instead refer to non-biological mechanisms. Furthermore, these mechanisms may actually be incompatible with current theories of biology. The particular non-biological mechanisms Carey was interested in were psychological or intentional causes. That is, she investigated and concluded that children think wishes and desires could be responsible for biological phenomena (e.g., "The gardener wanted the flower to be pink, so it became pink"). Whether participants would generate psychological mechanisms when repeatedly asked to explain inheritance was of interest. As mentioned earlier, other types of explanations that are incompatible with biological views of inheritance were also of interest (e.g., preformationism, vitalism, fantasy), but these types of responses were never generated.

Contrary to Carey's findings, participants rarely gave responses which indicated that they think psychological forces underlie biological inheritance. As seen in Table 3, only two children (one in Grade 2, one in Grade 4) revealed that they believe that intentions or wishes alone could affect transmission of traits (e.g., "She will be tall because she wants to be tall like her parents." S7: Grade 2). Other participants who generated intentional explanations in response to the biological questions stipulated that action was also necessary. Examples of action statements include: "People look more like their friends because they choose friends that look like them." (S48: Grade 4), and "The gardener wanted a red flower, but the manager found pink seeds, and they got a pink flower instead." (S15: Grade 2). Also included were examples of behaviors that could accidentally result in the trait (e.g., "Maybe this dog lost its ears in a fight." S10: Grade 2). When the item 9 (pail) is included in this analysis (see Table 3), 91% of all participants included intentional forces (e.g., Maybe he wanted to pail to be red...), but all of these participants also stipulated the action that must be taken (...and so he painted it).

By the omission of psychological ideas in their justifications, participants demonstrated that they understood that intentional forces are insufficient or inappropriate for explaining biological inheritance. This understanding was further supported by the ratings data whereby over 90% of participants did not endorse the psychological mechanisms for the puppy and the flower, and approximately 90% endorsed the mechanism as an explanation for color in an artifact. Clearly, almost all participants in all age groups distinguished situations where psychological but not biological explanations apply, and vice versa.

Theological

As a result of their Catholic education, children investigated in the current study received weekly religious instruction and the idea that God could intervene in worldly matters, including biological phenomena. Furthermore, these children tended to give very high ratings for the theological explanation in items 7 and 8. Therefore, it was expected that many children would generate explanations that included the concept of God and to do so for several questions. No information was requested concerning adults' religious background, but only a minority of adults endorsed the theological explanation for the puppy, flower, and pail. Thus, not many adults were expected to generate this explanation or to generate it consistently. Surprisingly, only 12 children and one adult alluded to God during the interview. These individuals invoked this idea an average of 1.46 questions ($\underline{SD}$ = .66) with nine of the 13 participants mentioning God in response to the open-ended question concerning how the flower got its color (see Appendix A: item 8). It is quite possible that participants were cued by probes in the immediately preceding item (i.e, they were asked to rate the theological explanation for color of a puppy) and transferred this idea to the flower scenario. The rare use of the theological explanation for the remainder of the interview may be due to the task itself. S. Gelman (1988) and Keil (1989) found that when a task presentation indicates that biological beliefs are the relevant ones, the children will use their biological knowledge more than other forms of knowledge.

Non-Causal Justifications

When requested to explain an event where the underlying cause is unknown or is not completely understood, people can react in one of two ways; they can rely on non-causal explanations, or they can say "I don't know." Although inheritance of traits is a phenomenon that individuals encounter regularly, the particular scenarios depicted in the interview may have been unfamiliar to some participants. Therefore, it was expected that participants would occasionally provide non-causal responses.

The extent to which non-causal approaches help people understand novel situations is somewhat variable. Three potentially effective approaches include statistical reasoning, analogical reasoning, and use of anecdotal evidence. Less effective approaches include reliance on superficial (i.e., perceptual) features to make inductions. Each of these approaches is discussed in turn.

Statistical reasoning. Two statistical concepts that were of particular interest in the current study include the concepts of averages (i.e., what is normal) and variation. It has been suggested that when people interact with the natural world, they are regularly presented with evidence that things tend to follow a certain pattern, but that there is also some variation in the degree to which things follow this pattern (e.g., Nisbett et al., 1993). Because inheritance of most traits is somewhat probabalistic, expression of traits is somewhat variable. As a result of exposure to such patterns, Nisbett et al. (1993) claimed that people develop statistical intuitions with regard to normality (i.e., average) and variation. In item 10 (Thinking about Homogeneity and Variance), all participants, except five children in Grade 2, demonstrated statistical intuitions. It stands to reason, therefore, that most participants would include these ideas in their responses to questions regarding inheritance and would use these ideas often.

In fact, the frequency with which statistical concepts were used was quite high: 81% of all participants included statistical ideas at least once in the interview (see Table 3). There was an effect of age on the frequency with which statistical ideas were generated, χ^2 (3, N= 128) = 9.01, $p < .005$, in that statistical ideas were used by fewer children in Grade 2 than in the other age groups ($p < .005$). Statistical concepts, such as variation and regression to the mean, were rarely emphasized in and of themselves. For example, comments such as "Characteristics tend to vary." (S78: Grade 6) were infrequent. Rather, statistical ideas were generally contextualized (e.g., "It is normal for dogs to have the same size of ears as its mother." S36: Grade 4).

Consistency with which statistical ideas were used did not vary across age groups and was lower than anticipated. In response to15questions, participants included a statistical concept 3.25 times (SD = 2.03), (see Table 4). Use of statistical concepts appeared to be affected by the nature of the items. Frequency of use was highest for questions in items 1 and 2, whereby participants were asked to predict the nature of a trait in infants that were not related to the targets (see Appendix A). With little information on which to rely, except shared species-ship, 48% of participants provided responses that referred to what is normal in the species, or to the fact that individuals within a species of animal can vary. In response to the question of how a pail got its color (see Appendix A: item 9), statistical responses were non-existent. Characteristics of artifacts are, for the most part, under the control of the maker and are not subject to same random processes that affect biological traits. Perhaps for this reason, participants did not generate statistical answers for this question.

Analogical Reasoning. In this form of reasoning, people interpret novel problems in terms of situations that are better understood. Drawing appropriate analogies depends on understanding and identifying parallels in the relations in the situations being compared. Even very young children have been shown to draw successful analogies in certain situations, but in other circumstances, even college students fail to do so (Siegler, 1998). In the current study, use of analogies was extremely rare. Only one individual in each of

Grades 2, 4, and university included an analogy in their answers (e.g., "People have different sizes of hearts, so horses might too." S17: Grade 2) and did so only once. Perhaps it never occurred to participants to draw on analogical reasoning to answer the questions and justify their answers.

Anecdotal Evidence. Use of anecdotal evidence entails relying on particular examples from one's own experience to make and justify predictions (e.g., "In my observations, people with short parents are short." S110: Adult). As seen in Table 3, frequency with which anecdotes were used varied as a function of age, χ^2 (3, N=128) = 8.32, $p < .05$. More children than adults included anecdotes in their answers ($p < .01$). On one hand, it is surprising that adults were so reluctant to make generalizations from their personal experience. As seen in item 10 (Thinking about Homogeneity and Variance), they were more willing than children to make inductions from a single observation. On the other hand, adults have a better understanding about biological inheritance than children, as evidenced by the frequency and consistency with which they mentioned genes in their responses, and this understanding may have over-ridden any temptation to rely on anecdotal evidence. The consistency with which anecdotal evidence was used was not dependent on age; participants who generated this type of response did so on an average of 1.91 questions (SD = 1.22) (see Table 4). Three types of questions that were most likely to evoke this type of explanation included the scenario comparing the appearance of people to friends versus parents, the scenario comparing the appearance of people to their parents versus grandparents, and when asked to predict a child's eye color based on information provided about the parents' eye color. Perhaps these are situations that individuals thought about on their own at one time or another.

Reliance on Perceptual Features. A number of researchers (e.g., Piaget) have suggested that thinking in young children can be affected by irrelevant, superficial information and that children presume such perceptual features to be causal. That is, they have been characterized as being appearance-bound in their reasoning. As seen in Table 3, few participants mentioned perceptual features of the stimuli in their responses. Although perceptual features were sometimes emphasized in the probes (e.g., color of dog and horse in items 1 and 2), only 23% of all participants made reference to some perceptual aspect of the stimuli. Furthermore, they stipulated that such information is irrelevant in making predictions, or made correlational types of statements (e.g., "If the dog and the puppy share the same color, they could share small ears."). None of the participants made causal statements linking these features to other features. Perceptual features were alluded to an average of 1.70 times (SD = 1.15), mostly in response to questions in items 1 and 2, where they were cued to notice color. They rarely provided this type of information in response to other questions.

Proportion of Each Category of Explanations

Overall, although participants were similar in terms of the number of different types of explanations they generated, there were some age-related differences in terms of the frequency and consistency with which various types of explanations were generated. Shown in Table 5 are the proportion of questions to which explanations from each of these major categories were generated. Varying across age group were the proportion of questions whereby participants generated an explanation that is congruous with biological theories of inheritance (with and without a clear causal mechanism). For the remaining types of explanations, proportions did not vary across age groups. Each type of response is briefly reviewed.

All participants, with exception of one child in each of Grades 2 and 4, were able to generate an explanation that included a clear, causal mechanism that is congruent with biological theories of inheritance (see Table 3). However, in response to the 14 questions for which biological mechanisms apply, the proportion of answers that incorporated a clear mechanism increased with age, $F(3,124) = 79.3$, $p < .001$. As seen in Table 5, adults included these types of explanations in the majority of their answers. This level of inclusion was more than double than was seen in the responses of children in Grades 4 and 6 ($p < .001$), who in turn included clear biological explanations in slightly more answers than children in Grade 2. Thus, the youngest children had the most problems articulating a clear causal mechanism, and this ability appears to develop relatively slowly. Part of this developmental timetable appears to be dictated by growing knowledge about genes, and part may be due to growing knowledge about how to communicate what is known with clarity.

Assuming that the adults in this study had both types of knowledge, they, along with children, did not always implement it. At least once in the interview, all participants generated a response whereby the causal mechanism was unclear. As seen in Table 5, however, adults were generally careful to avoid generating this type of response, while children generated this type of response for almost half of their responses. In other words, the tendency to generate such responses decreased with age, $F(3,124) = 23.78$, $p < .001$.

The fact that children sometimes excluded mechanisms from their answers appears to be due to a lack of specific biological knowledge of inheritance, rather than a general misconstrual of inheritance. Only a few children ever intimated that they construed the scenarios depicted in the interview from a non-biological point of view. During the course of the interview, only a few participants from all three grades generated a response that included either an intentional or theological mechanism, and never generated explanations that were fantastical (e.g., fairies, magic). On average, intentional explanations were included in less than 1% of all responses generated by each age group. Similarly, in only 1% of responses did participants refer to theological mechanisms. Therefore, it is reasonable to assume that their vague references to kinship, species-ship, birth, and growth probably connotes biological mechanisms.

From time to time, almost all participants (91%) provided responses that included a non-causal component. As seen in Table 5, an average of 24% of all the responses were of this nature. Noncausal ideas were rarely generated in isolation, however. Only 6% of noncausal responses were generated in isolation, and of these, most were anecdotal. Generally, participants from all age groups recognized that the function of these types of ideas are to support causal arguments.

Finally, a fraction of responses comprised the answers "not sure," "I don't know," or generated responses that were too ambiguous to be coded (see Table 5: Not Sure/Indeterminate). The frequency with which participants generated this type of response decreased with age, χ^2 (3, N=128) = 34.10, p < .001. Most children in Grade 2 (87%) responded in this manner at least once in the interview, as did 56% and 44% of children in Grades 4 and 6. Sixteen percent of adults also had some difficulties coming up with an explanation for one or more of the 15 questions. The extent of these difficulties decreased significantly with age as well, $F(3,124)=20.49$, $p < .001$. Generally, the consistency with which this response was generated decreased with age, presumably due to participants' increasing knowledge about inheritance.

DISCUSSION

People are inundated with biological phenomena on a daily basis and are faced with the task of identifying and explaining such phenomena. The current view of conceptual understanding in the developmental literature is that when we try to identify and explain what we observe, we understand it within the context of a theoretical framework. Biological understanding entails knowing the difference between living and non-living things, including knowing which processes apply to biological entities, but not artifacts and vice versa. That is, one must realize that biological processes tend to operate outside the forces of mechanical causation and that biological processes do not apply to artifacts. Interpreting biological phenomena from a theoretical framework of physical laws would result in misunderstanding. Furthermore, one must understand that biological processes are not subject to forces of belief or desire. In other words, biological understanding requires that explanations of biological phenomena not be situated within a psychological theoretical framework, otherwise such phenomena will be misconstrued as being intentionally driven.

The focus of this study was on understanding of biological inheritance and the goals were two fold. One goal, typical of most developmental research, was that of describing age-related differences in knowledge. In particular, an intention of this study was to ascertain age-related differences in knowledge about inheritance. This objective was achieved by interviewing participants in Grades 2, 4, 6, and university students, using a series of questions concerning inheritance of physical traits across one or two generations. Investigated were age-related differences in knowledge about genes and their role in transmission of traits, the environment and its impact on how traits are expressed, and their intuitions regarding homogeneity and variance of traits. Also investigated were age-related differences in the types of explanations participants endorsed to explain inheritance as well as the types of explanations participants generated in response to the series of questions in the interview.

The second goal, often omitted from developmental research, was that of describing variability of thinking within age groups and within individuals. Possessing a biological framework does not necessarily preclude one from concurrently using other frameworks, be they psychological, theological, or any other type. That is, it is not necessarily the case that once one framework is adopted that others are abandoned. However, it is possible that once one achieves a scientific understanding of biological phenomena, less adequate types of explanations are used with less frequency. Thus, a related issue in this study was whether children and adults possess and simultaneously maintain a number of different theoretical frameworks when repeatedly questioned about inheritance. In this study, variability was addressed by looking at the number of different types of explanations endorsed and generated by individuals within each age group, and the consistency with which these ideas were expressed during the interviewing process. Research focused on multiple frameworks, rather than a single framework, can supplement rather than detract from research focused on age-related differences. In the next section, I summarize my findings and discuss the implications of adopting a multi-framework stance.

Summary of Research

One hundred and twenty-eight participants, from Grades 2, 4, 6, and university were extensively and systematically interviewed on the topic of inheritance. The interview was comprised of three types of tasks: Generation, Endorsement, and Background Knowledge. Of interest was not only participants' knowledge about inheritance, but their inclination to use it when asked repeatedly about transmission of physical traits. Background knowledge is discussed first, followed by the Endorsement and Generation Tasks

Background Knowledge

The focus in this section was on age-related differences in knowledge about genes, the role of the environment in trait expression, and intuitions regarding homogeneity and variance of traits. Some findings regarding age-related differences were anticipated, whereas others were not.

Knowledge About Genes

Not surprisingly, more adults than children knew about genes, and more children from the older grades (Grades 4 and 6) had this knowledge than children in Grade 2. Such age effects are likely the result of science learning. Children have less opportunity than adults to learn formally and informally about inheritance. In the province where these children attended school, instruction of genetics is not introduced into the curriculum until late elementary grades and advanced technical knowledge is usually not introduced until high school. Although research on cloning and the controversies surrounding cloning received extensive coverage in the media during the time of this interview, young children may not have possessed sufficient background knowledge to benefit from exposure to such news reports. Furthermore, children typically do not even think to ask their parents about things such as genes unless they hear about it first in school or through some other source such as the news. What was surprising then, was the quality of knowledge among children who knew about genes. Although they possessed little knowledge about genes at the cellular level, they, like adults, knew some of the functions of genes, where they originate, and the kinds of things that possess genes. In future research, participants should be asked where they learned about genes. This information could provide insights regarding the range of situations in which participants learn about genetic inheritance. For example, is this information picked up incidentally as result of making a particular observation that needed explaining, or is this information presented systematically in a science classroom?

Knowledge About the Environment

The extent to which the expression of two types of traits can be influenced by the environment was also investigated. One trait, height, is somewhat variable, not only within populations, but also within one's lifetime. Up to a point, it can be constrained or enhanced by environmental manipulations. The other trait, number of arms, is highly canalized and not easily affected by environmental variations. Participants from all age groups expressed similar opinions regarding the impact the environment has on these traits, in the sense that they agreed that height, but not number of arms, can be influenced by "normal" environmental fluctuations. Those who claimed that height can be changed provided similar examples of factors that affect growth, such as food. Those who claimed that number of arms can be changed stipulated that extremely rare environmental conditions must exist for such an abnormality to be expressed. To some extent, these intuitions must be acquired through daily observations of environmental variations in conjunction with variation or homogeneity of traits. Instruction about environmental influences on traits is most sensibly done in context of instruction about genetic influences on traits. Because it was clear that many children had not yet received formal instruction on genetics, they must have acquired their knowledge about the impact of the environment through other sources.

Knowledge about Homogeneity and Variance

Again this type of knowledge appears to be intuitive in the sense that it is acquired through daily exposure to various degrees of natural variation in the environment, although it can be enhanced through formal statistical training (Fong, Krantz, & Nisbett, 1993). Research has been conducted on adults' statistical intuitions (e.g.,Nisbett, et al., 1993), but little has been done on this type of thinking in young children. It was considered essential to address these intuitions in the current study because how one thinks about inheritance may be influenced by one's sense of natural variation. In the item designed to measure this knowledge, children from all age groups performed very much as adults. For example, based on a single observation, they were most willing to generalize a trait that was inherently invariable, and least willing to generalize a trait that was inherently variable. Also, in their justifications, most participants incorporated statistical reasons. Even children as young as those in Grade 2 were not restricted to deterministic reasoning when thinking about probabalistic events.

Overall, children in this study were in some ways comparable to adults in their background knowledge. For knowledge that appears to be acquired though everyday exposure to natural world, children were similar to adults. Intuitive knowledge regarding variation and homogeneity of traits in normal environments appears to emerge early, thereby enabling children to draw on this knowledge when thinking about inheritance of traits. Specific knowledge about genes is not intuitive. Learning about genes requires that information about genes must be explicitly presented to the learner, either in the classroom, or in informal contexts (e.g., T.V.). Fewer children than adults had this knowledge, but children who did have it knew more about function and origin than expected. It is not certain where they acquired their information. It is possible that they got all their information from several sources, or they heard about genes from one source and were able to rely on their theories of biology to make further inferences about the functioning of genes.

The Endorsement Task

Number and types of explanations of inheritance that participants endorsed was of interest in this task. The endorsement section was set up to enable participants to subscribe to up to seven explanations of inheritance simultaneously, ranging from those that are scientifically endorsed (e.g., genetics, environment) to those that are not (e.g., psychological, fantasy). Variability of endorsement was measured in terms of number of explanations endorsed. For biological entities, younger participants (children in Grades 2 and 4) endorsed more explanations than older participants. Yet, it does not appear to be simply the case that along with increasing knowledge about genetics comes an increasing tendency to rule out alternative explanations. For example, children in Grades 4 and 6 were comparable in their genetic knowledge, but different in terms of their willingness to rule out other explanations. Thus, endorsing one explanation does not always necessitate rejecting others. Perhaps explanations are evaluated independently of one another, and younger children are slower to abandon some explanations. This interpretation would be quite easily accommodated by an overlapping wave model but difficult to reconcile with a stage model of conceptual development. In this study, it was found that approximately half of the children in Grade 2 and 4 endorsed three or more explanations, whereas only a small fraction of older participants concurrently maintained as many explanations. For the flower, endorsement trends were similar. There was more agreement among age groups concerning the number of explanations endorsed for the pail. Causes underlying color of an artifact are perhaps more apparent than causes underlying color of biological entities, and participants in all age groups shared similar knowledge concerning these causes.

The particular types of explanations preferred varied with age but only for biological entities. There was much agreement among adults concerning the appropriateness of the genetic mechanism for both the flower and the puppy; most adults endorsed this explanation for these two entities. No other explanation was endorsed by the majority of adults. It should be pointed out, however, that this does not mean that adults endorsed the genetic explanation to the exclusion of others. About half endorsed other explanations as well. Children were less willing to endorse the genetic mechanism, especially for the flower. As in Springer and Keil's study (1991), many children did not possess enough technical knowledge about genes to endorse this explanation. Children generally found the theological explanation more acceptable than adults, perhaps reflecting one aspect of the education that they receive on at least a weekly basis in school. One commonality that was found across all age groups was the reluctance to endorse the psychological explanation. Regardless of age, the idea that intentions could somehow influence color in biological entities was considered unacceptable by almost all participants. In fact, more children in Grades 2 and 4 endorsed vitalistic and fantastical explanations (i.e., fairies) than the psychological explanation. Of the few that endorsed that latter, only one indicated that he thought that intentions could affect a biological trait. Thus, except for this one child, inheritance did not appear to be construed from a psychological framework.

The Generation Task

The generation task involved open-ended questions, thus enabling participants to express ideas other than those presented in the Endorsement Task. The ideas generated by participants in all age groups were categorized into five major categories: (a) congruous with biological theories of inheritance, and included a clear causal mechanism, (b) congruous with biological theories, but lacking a clear causal mechanism, (c) psychological or behavioral, (d) theological, or (e) noncausal. Responses were further classified into sub-categories, when applicable. A variety of ideas were generated during the course of the interview. On average, participants at all age levels generated over six different types of ideas. Thus, variability per se did not change with age. Furthermore, in all four age groups, each of these categories was expressed at least once, although psychological and behavioral responses were usually restricted to the question concerning an artifact. Generally, less adequate explanations were not totally abandoned and replaced by more adequate explanations. A developmental trend that was notable in this study was changes in terms of the consistency with which some of these ideas were expressed. Children's responses, although mostly congruent with biological theories on inheritance, were often vague in terms of causal mechanism. There was an increased tendency to use clearer explanations between Grade 2 and Grade 6, but use of vague explanations did not decline during this period. By adulthood, responses were mostly congruent and included a clear causal mechanism. Increasing tendency to generate clear responses likely reflects growing scientific knowledge about genetics and growing knowledge about communicating your thoughts. Despite having at hand knowledge about genetics, adults did not use this knowledge with perfect consistency, however. They generated other types of explanations as well. Perhaps this result obtains from not realizing that genes apply to every single situation depicted in the interview (e.g., when individuals share species-ship but not kinship), or because adults were abiding to some sort of conversational rule concerning redundancy.

Implications of Research and Future Directions

What was apparent in this study is that, with development, came increased clarity and generality in the application of biological thinking. Conceptual development, at least in the area of biological reasoning about inheritance, did not entail replacement of one form of thinking with another. Also witnessed within each age group were variable forms of thinking, albeit, the majority of these forms were biological in nature. Very few individuals at any age level produced only one type of response when presented with a series of conceptually related questions. Therefore, trying to discover "the way" individuals think at each age may not be a fruitful exercise and portraying biological understanding as monolithic ways of reasoning for extended periods of time may not provide the full developmental picture. As Siegler (1996) pointed out, rather than portraying conceptual development in terms of qualitative movements, it may be better thought of as conceptual ecology, with changing distributions and frequencies of ways of thinking that compete or even sometimes complement one another. In the current study, having knowledge about genes did not necessarily entail less variety, but it did result in a shift of focus from less adequate to more adequate explanations.

Future research needs to be aimed at discovering how variability enables or even promotes conceptual development. In the areas of math, children in the process of discovering new strategies display particularly variable performance before and following when a discovery is made (Siegler, 1994). Furthermore, children who display varied ways of thinking are more likely to learn from instruction on particular concepts than children who are less varied in their approaches to math problems (Graham & Perry, 1993). Perhaps the same trend is true of biological understanding.

An interesting finding in the current study was also the extent of similarity in thinking between different age groups. When children try to explain something they do not quite understand, they do not generate just any type of explanation. Explanations, at least those generated by children in the current study, were largely constrained to explanations that are consistent with current scientific theories. Thus, future research needs to be aimed at not only clarifying how children form their explanations, but what constrains their explanations. As alluded to earlier, some researchers have found that when a task presentation indicates that biological beliefs are the relevant ones, the children will use their biological knowledge more than other forms of knowledge (e.g., S. Gelman, 1988; Keil, 1989). How do they know to do this? How do children's theoretical framework in biology enable variability in thinking, but constrained variability?

Finally, needed is more research designed to determine how explanations are chosen. If multiple explanations coexist, then a choice must be made among the alternatives when trying to answer a question. With regard to biological understanding, does metacognitive awareness of one's explanations and their applicability to various scenarios play a role in choice? Or, is it as it is in the area of math, whereby automatic processes also take part in choice? Finally, do conversational rules affect choice in the interview process?

In the current study, participants' justifications were somewhat helpful in trying to describe how individuals at different ages think about biological inheritance, especially in the context of an interview whereby participants were repeatedly questioned about the same topic. Other researchers agree that eliciting and analyzing explanations is a revealing research method because in domains such as biology, knowledge is intimately tied to the task of making sense of the natural world. Sense-making is essentially the function of explanation (Wellman, Hickling, & Schultz, 1997). To achieve a fuller understanding of development of biological thinking, similar types of research need to be conducted on children's thinking with regard to several types of biological phenomena. Questions that could be addressed include: What are the sources of variability? What are the commonalities in thinking about different biological phenomena? Is it the case that variability in thinking is expressed in all types of biological reasoning or just some areas? Would variability of explanations in another biological domain be constrained in the same way as was seen with regard to inheritance in this study? What conditions are necessary for variability? Does variability depend on the knowledge domain itself, or on the knower? For example, if this research were extended to geneticists, would variability be expressed to the same degree, to a less degree, or not at all? If variability is maintained, how does growing knowledge in a domain affect choice among alternative explanations? Once I replaced the notion of "the way" of thinking about biological phenomena with the notion of "variability in thinking," these are but a few questions that came to mind. I think that a change of focus in this field of research could be productive in not only generating questions such as these, but in providing answers to some unanswered questions concerning conceptual development.

Table 1

Number and Percentages of Participants Who Demonstrated Knowledge About Different Aspects of Genes (Questions 12b-12f)

	Question	Response Type	Grade 2	Grade 4	Grade 6	Adult
Number of Participants Who Had Knowledge About Genes			**1**	**13**	**16**	**32**
12b.	**What do genes do?**	**Looks**	1 (100)	13 (100)	16 (100)	31 (97)
		Behavior/Intelligence	-	5 (38)	7 (44)	23 (72)
12c.	**What kinds of things have genes?**	**People**	1 (100)	13 (100)	16 (100)	32 (100)
		Animals	1 (100)	13 (100)	16 (100)	31 (97)
		Plants	1 (100)	8 (62)	12 (75)	30 (94)
12d.	**Where do we get our genes from?**	**Parents**	-	5 (38)	5 (31)	24 (75)
		Ancestors	1 (100)	8 (62)	10 (62)	8 (25)
		Mother	-	-	1 (7)	-
12e.	**Where are genes found in the body?**	**All Cells**	-	-	2 (12)	26 (82)
		Blood/Whole Body	1 (100)	5 (38)	9 (56)	3 (9)
		Body Part	-	2 (16)	4 (25)	1 (3)
		Not Sure	-	6 (46)	1 (7)	2 (6)
12f.	**Is it possible to see a gene?**	**Yes**	1 (100)	7 (54)	11 (78)	22 (69)
		How?-Microscope	1 (100)	3 (19)	10 (63)	22 (69)
		-Traits	-	3 (8)	1 (6)	3 (9)
		-Not Sure				
		No	-	5 (38)	3 (19)	7 (22)
		Why -Too Small	-	2 (16)	1 (6)	5 (16)
		Not?-Not Sure	-	3 (8)	2 (13)	2 (16)

Table 2

Proportion of Participants in Each Age Group Whose Endorsements Across Entities Follow a Distinguishable Pattern

	Group			
Rating	Grade 2	Grade 4	Grade 6	Adult
Genetic				
Endorsed For All Entities	6	0	6	0
Endorsed For None of the Entities	34	41	31	0
Endorsed For Biological Entities Only	6	12	18	94
Endorsed For Pail Only	0	12	3	0
Environmental				
Endorsed For All Entities	9	12	9	22
Endorsed For None of the Entities	41	31	31	16
Endorsed For Biological Entity Only	12	9	6	3
Endorsed For Pail Only	6	9	9	44
Psychological				
Endorsed For All Entities	0	0	0	0
Endorsed For None of the Entities	12	9	3	3
Endorsed For Biological Entities Only	0	0	0	0
Endorsed For Pail Only	59	78	91	91
God				
Endorsed For All Entities	44	38	19	6
Endorsed For None of the Entities	12	6	34	88
Endorsed For Biological Entities Only	12	53	28	9
Endorsed For Pail Only	0	0	0	0
Preformation				
Endorsed For All Entities	19	6	16	0
Endorsed For None of the Entities	16	41	44	91
Endorsed For Biological Entities Only	25	28	6	3
Endorsed For Pail Only	3	0	0	0
Vitalism				
Endorsed For All Entities	0	3	0	0
Endorsed For None of the Entities	56	78	100	100
Endorsed For Biological Entities Only	9	3	0	0
Endorsed For Artifact Only	0	0	0	0
Fairy				
Endorsed For All Entities	12	0	0	0
Endorsed For None of the Entities	75	100	100	100
Endorsed For Biological Entities Only	0	0	0	0
Endorsed For Pail Only	0	0	0	0

Table 3

Frequency With Which Each Explanation Type Was Generated At Least Once

	Group			
	Grade 2	Grade 4	Grade 6	Adult
Congruous with Biological Theory-Clear Mechanisms	**31**	**31**	**32**	**32**
Genetic	1	6	10	32
Genetic Related	6	7	12	12
Physiological	8	13	16	2
Environmental	30	29	29	28
Congruous with Biological Theory-Unclear Mechanism	**32**	**32**	**32**	**31**
Kinship alone	30	31	32	23
Species-ship alone	18	15	18	17
Growth	8	9	4	0
Birth	26	25	21	3
Psychological	**1**	**1**	**0**	**0**
Behavioral[a]	**28**	**30**	**29**	**30**
Behavioral[b]	**6**	**5**	**3**	**2**
Theological	**5**	**4**	**3**	**1**
Noncausal	**26**	**29**	**31**	**31**
Statistical	22	27	25	30
Analogical	1	1	0	1
Anecdotal	15	11	14	5
Perceptual Features	9	9	5	7
Not Sure/Indeterminate	**28**	**18**	**14**	**5**

Note. Frequency refers to the number of participants in each age group (n=32) who generated the response at least once in the interview.

a. Number of participants who generated a behavioral explanation for 15 questions (pail question included.).

b. Number of participants who generated a behavioral explanation for 14 questions (pail question not included)

Table 4

Consistency of Generation of Each Explanation Type as a Function of Age

	Average Number of Questions Response was Generated				Number of Participants who Generated Response on 25% or fewer Question				Number of Participants who Generated Response on 26% to 50% Questions				Number of Participants who Generated Response on %51+Questions			
	G2	G4	G6	A	G2	G4	G6	A	G2	G4	G6	A	G2	G4	G6	A
Congruous with Biological Theory–Clear Mechanism	**2.13**	**3.45**	**4.75**	**11.12**	**27**	**21**	**15**	**0**	**4**	**7**	**10**	**4**	**0**	**3**	**7**	**28**
Genetic Explanation[b]	2.05	3.57	5.30	10.40	1	3	3	0	0	3	3	4	0	0	4	28
Genetic Related[b]	1.67	2.43	2.50	1.50	6	5	9	12	0	2	3	0	0	0	0	0
Physiological[b]	1.75	2.38	1.94	1.00	7	10	14	2	1	3	2	0	0	0	0	0
Environmental[a]	1.67	1.83	1.90	1.50	29	28	25	28	1	1	4	0	0	0	0	0
Congruous with Biological Theory--unclear Mechanism	**6.63**	**7.43**	**7.03**	**1.96**	**3**	**3**	**4**	**30**	**18**	**12**	**14**	**2**	**11**	**17**	**14**	**0**
Kinship alone[b]	4.12	5.23	5.16	1.65	19	13	10	13	11	13	22	10	0	5	0	0
Species-ship alone[b]	1.72	1.87	1.28	1.35	18	15	18	17	0	0	0	0	0	0	0	0
Growth[b]	1.25	1.22	1.00	0.00	8	9	4	0	0	0	0	0	0	0	0	0
Birth[b]	2.27	2.64	1.61	1.00	24	20	20	3	2	5	1	0	0	0	0	0

Note. Tabulations for average number of questions each response was generated includes only those participants who generated the explanation at least once.

a..Explanation could apply to all 15 questions.

b. Explanation could apply to 14 questions–this explanation would not make sense in the context of item 9: color of pail

Table 4 (continued)

Consistency of Generation of Each Explanation Type As a Function of Age

	Average Number of Questions Response was Generated				Number of Participants who Generated Response on 25% or fewer Question				Number of Participants who Generated Response on 26% to 50% Questions				Number of Participants who Generated Response on 51% +			
	G2	G4	G6	A	G2	G4	G6	A	G2	G4	G6	A	G2	G4	G6	A
Psychological[a]	1.00	2.00	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Behavioral[b]	1.17	1.60	1.00	1.00	6	5	3	2	0	0	0	0	0	0	0	0
Behavioral[a]	1.21	1.14	1.10	1.07	28	29	29	30	0	0	0	0	0	0	0	0
Theological[a]	2.00	1.25	1.10	1.00	5	4	3	1	0	0	0	0	0	0	0	0
Noncausal[c]	2.05	1.88	1.75	1.50	16	17	20	11	2	0	1	1	0	0	0	0
Noncausal[d]	3.73	3.72	3.93	4.12	12	15	14	16	13	13	16	12	1	1	1	3
Statistical[ad]	3.18	2.59	3.38	3.77	16	20	13	16	4	7	12	12	2	0	0	2
Analogical[bd]	1.00	1.00	0.00	1.00	1	1	0	1	0	0	0	0	0	0	0	0
Anecdotal[ad]	1.53	2.54	1.71	2.00	14	8	13	4	1	3	1	1	0	0	0	0
Perceptuaa[bd]	2.22	1.67	1.60	1.14	8	8	5	7	1	1	0	0	0	0	0	0
Not Sure[a]	3.82	2.56	1.42	2.40	13	13	14	3	13	5	0	2	2	0	0	0

Note. Tabulations for average number of questions each response was generated includes only those participants who generated the explanation at least once.

a. *Explanation could apply to all 15 questions --includes item 9: color of pail*

b. Explanation could apply to 14 questions

c. These non-causal responses are generated without reference to other causal mechanisms

d. These non-causal responses are generated in the context of other causal mechanisms

Table 5

Proportion of Explanations Generated

	Group			
	Grade 2	Grade 4	Grade 6	Adult
Congruous with Biological[b] Theory-Clear Mechanisms	.15	.24	.34	.80
Congruous with Biological[b] Theory-Unclear Mechanism	.47	.53	.49	.12
Psychological[a]	.005	.003	.00	.00
Behavioral[a]	.08	.08	.07	.07
Theological[a]	.02	.01	.001	.001
Noncausal(contextualized)[a]	.20	.23	.25	.27
Noncausal (without reference to other causes)[a]	.08	.07	.08	.04
Indeterminate/Not Sure[a]	.24	.10	.05	.03

Note. Proportion of responses is the proportion of questions (out of 14 or 15) the explanation type was generated

a. Explanation type could apply to all 15 questions.

b. Explanation type could apply to 14 of the 15 questions.

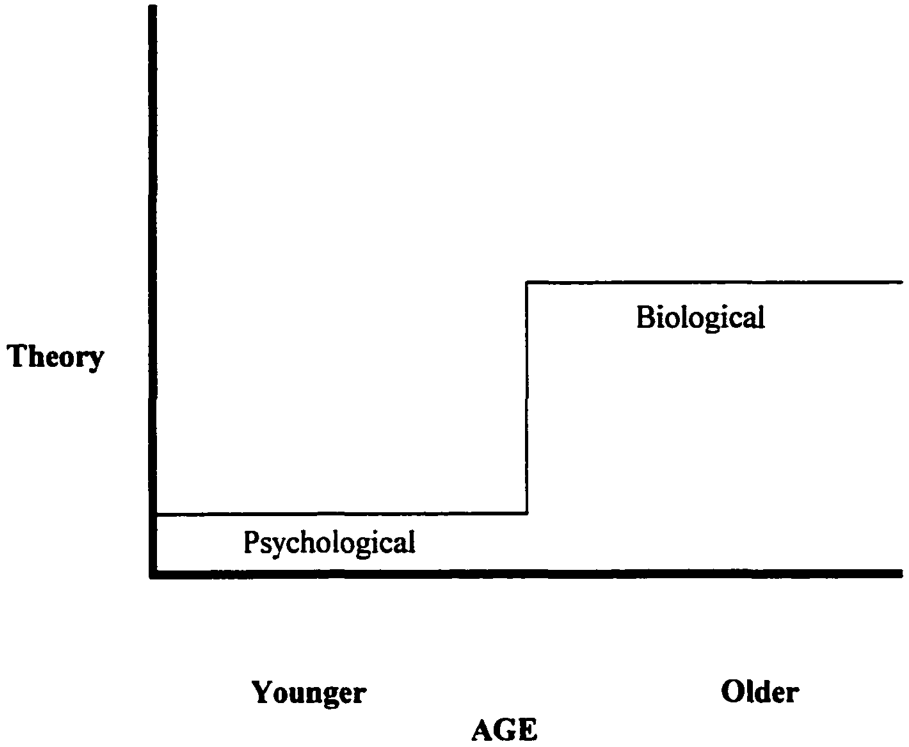


Figure 1: Stage model of conceptual development in biology (Siegler, 1996)

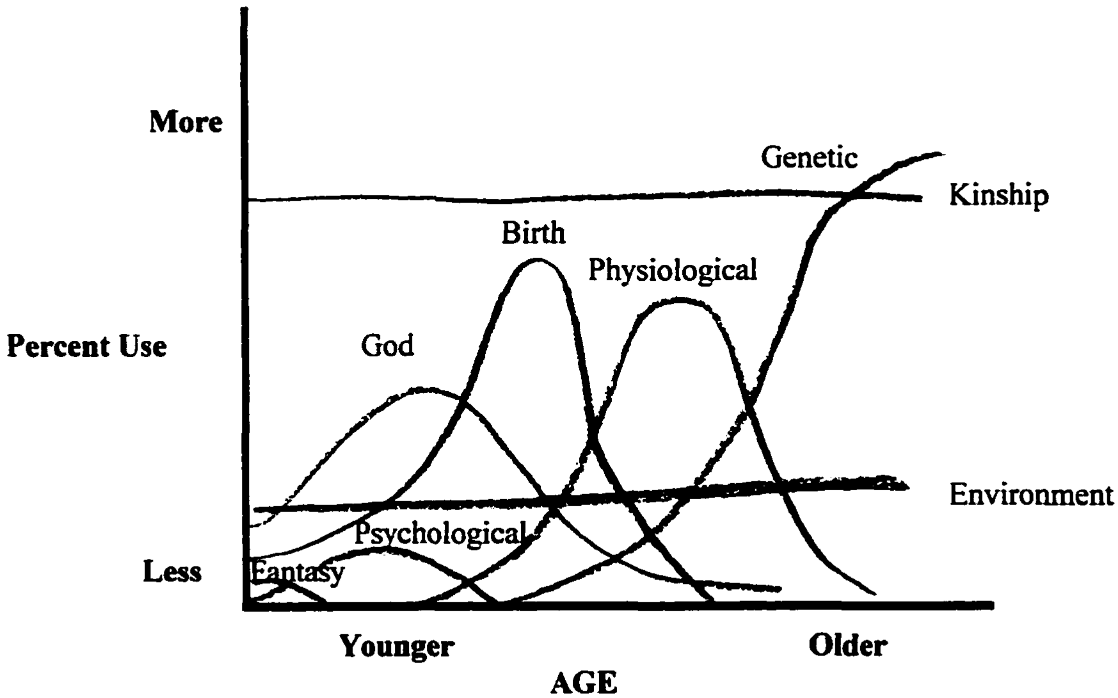


Figure 2: Hypothetical overlapping waves model of conceptual development in biology (based on Siegler, 1996)

Figure 3
Number of Participants Who Chose Each Option in Item 11: Height

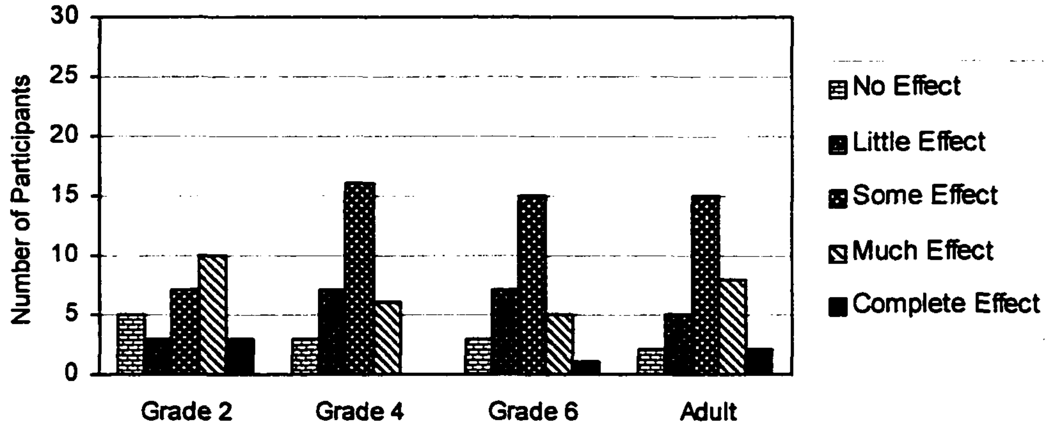


Figure 4
Number of Participants Who Chose Each Option in Item 11: Number of Arms

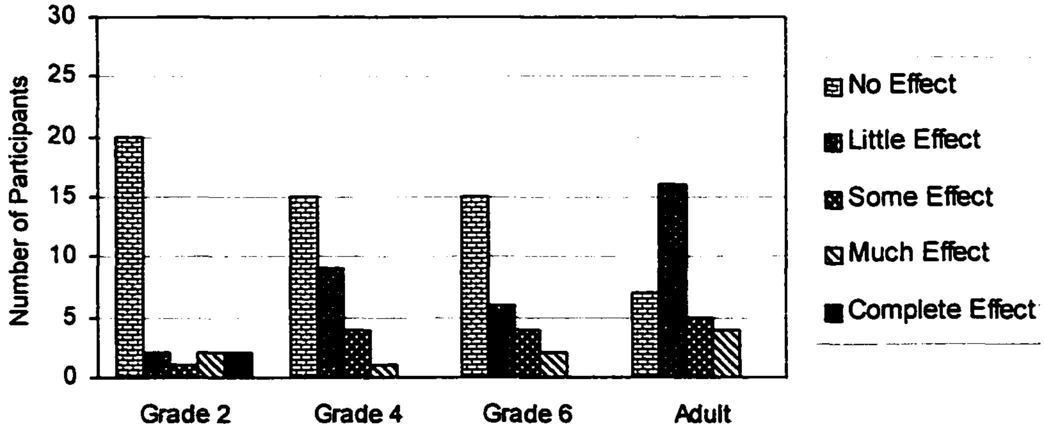


Figure 5
Number of Participants Who Generalized the Property To More Than Half or All Other Cases

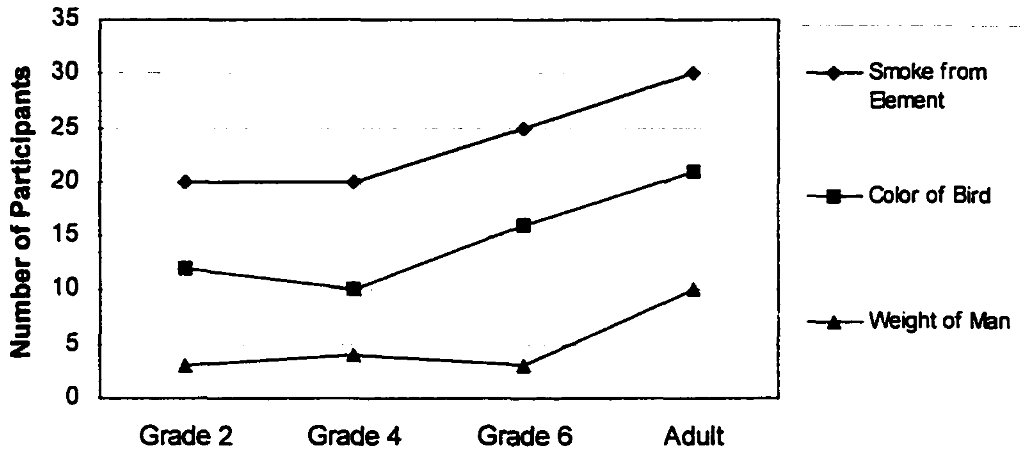


Figure 6
Use of Statistical Concepts in Item 10

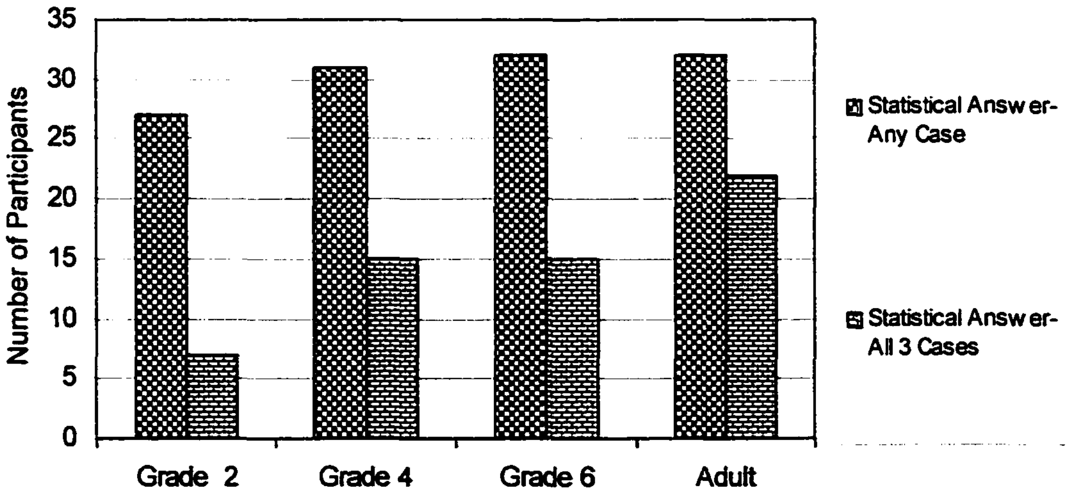


Figure 7
Average Number of Explanations Endorsed: Age by Entity

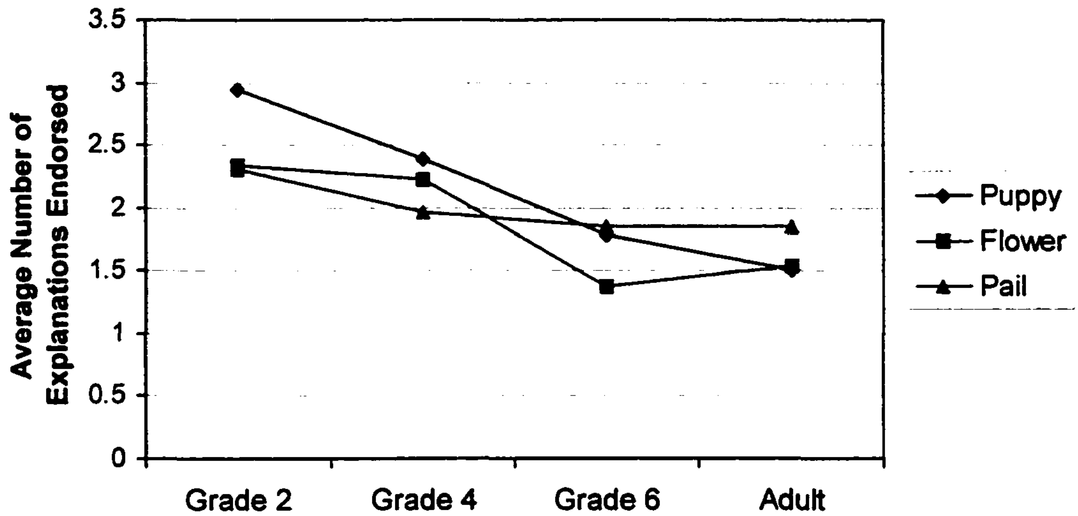


Figure 8
Percentage of Participants Who Endorsed the Genetic Explanation as Function of Age and Entity

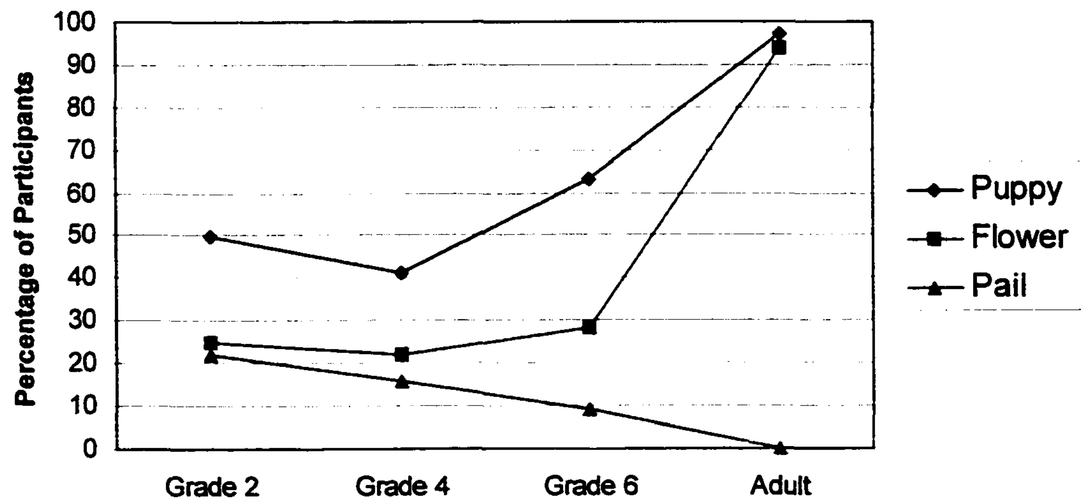


Figure 9
Percentage of Participants Who Endorsed the Environmental Explanation as Function of Age and Entity

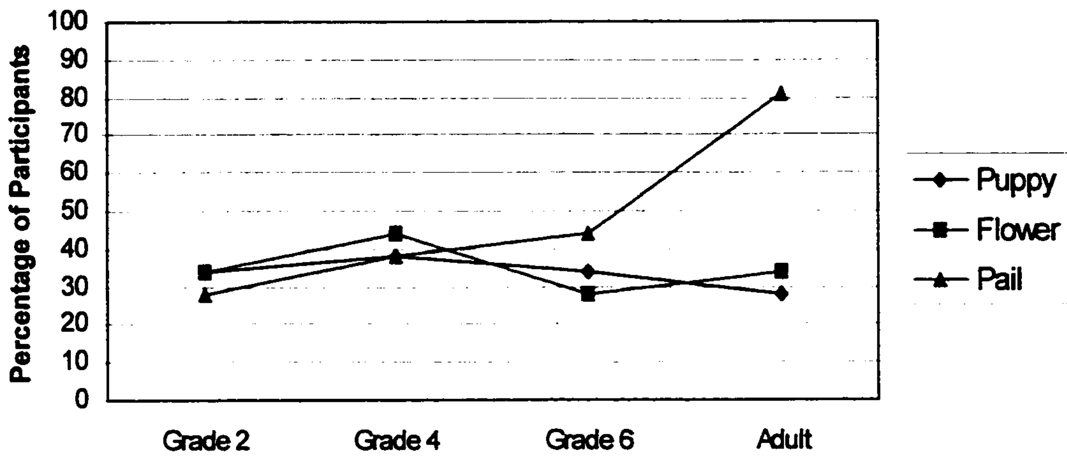


Figure 10
Percentage of Participants Who Endorsed the Psychological Explanation as Function of Age and Entity

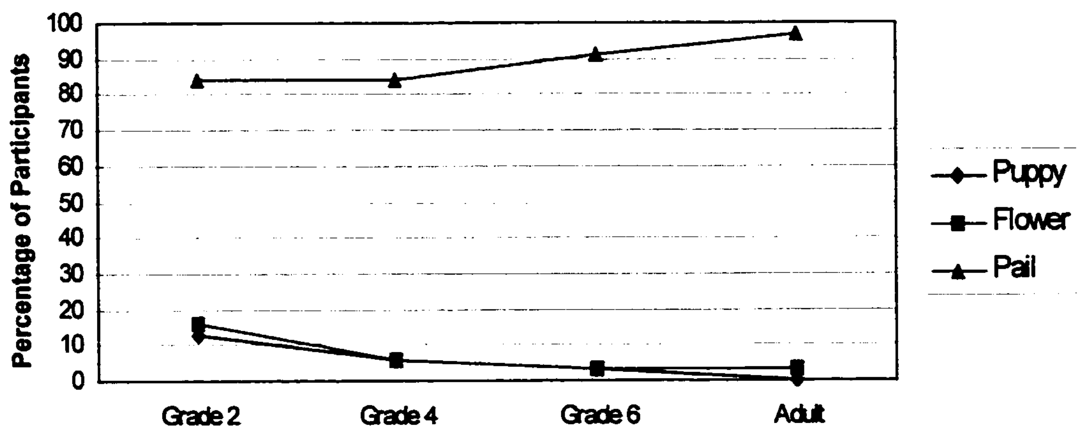


Figure 11
Percentage of Participants Who Endorsed God as an Explanation as Function of Age and Entity

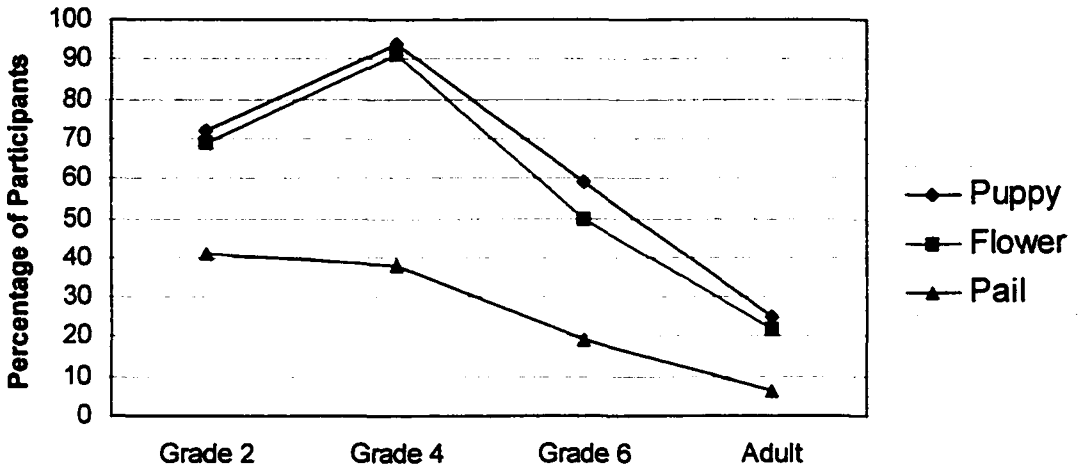


Figure 12
Percentage of Participants Who Endorsed Preformation as an Explanation as Function of Age and Entity

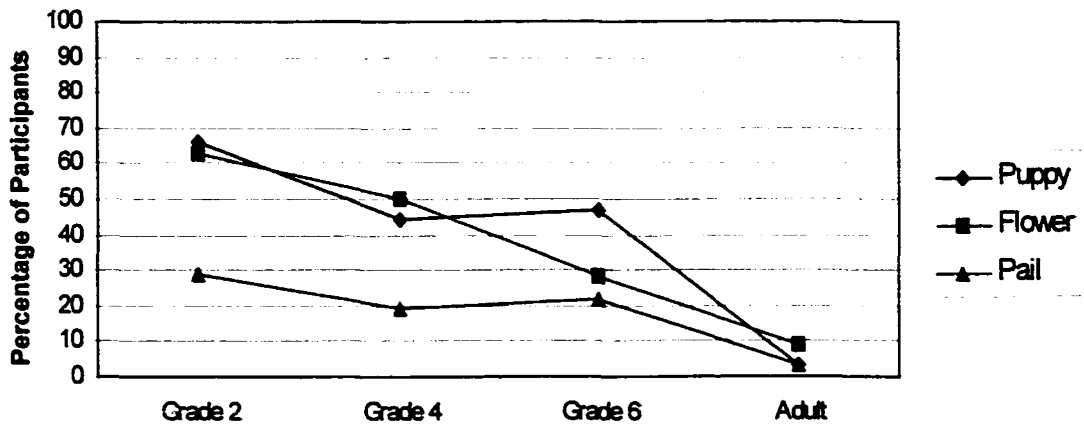


Figure 13
Percentage of Participants Who Endorsed Vitalism as an Explanation as Function of Age and Entity

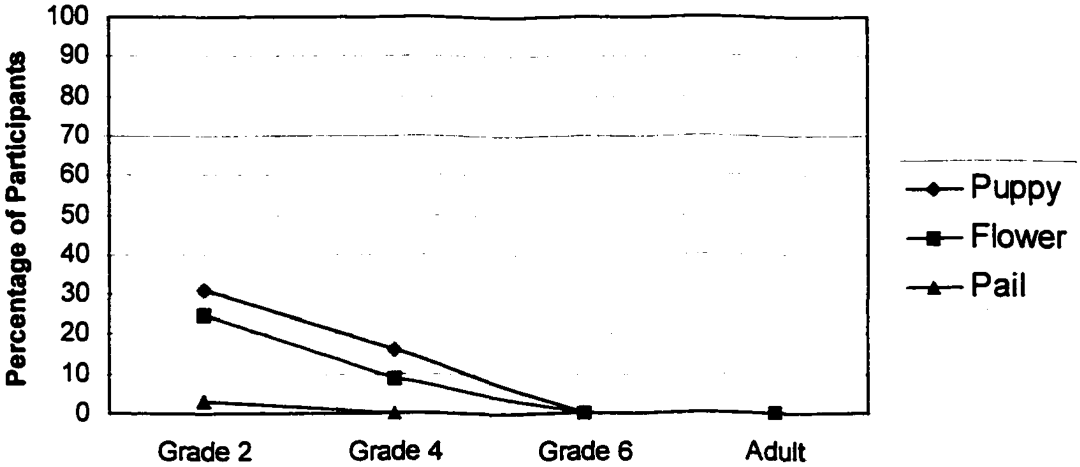


Figure 14
Percentage of Participants Who Endorsed Fairies as an Explanation as Function of Age and Entity

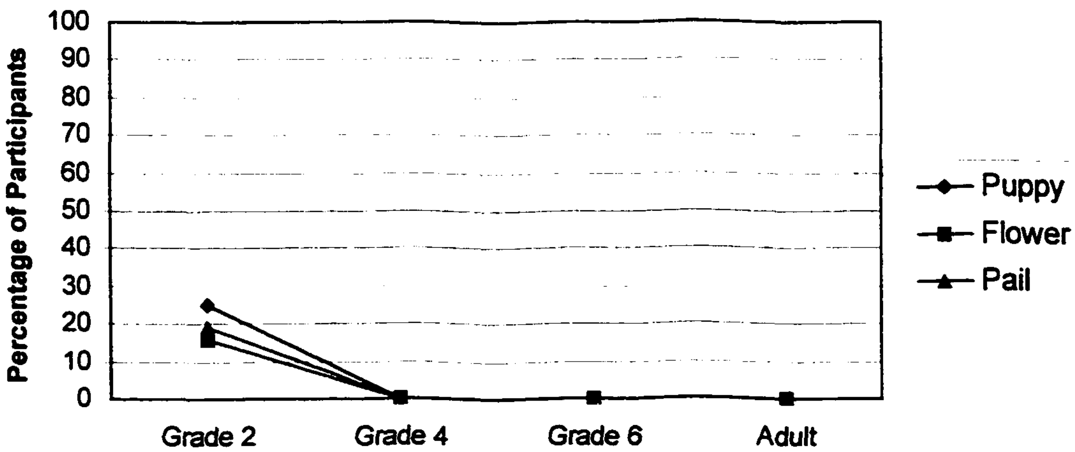


Figure 15
Percentage of Participants Per Age Group
Who Endorsed Each Explanation: Puppy

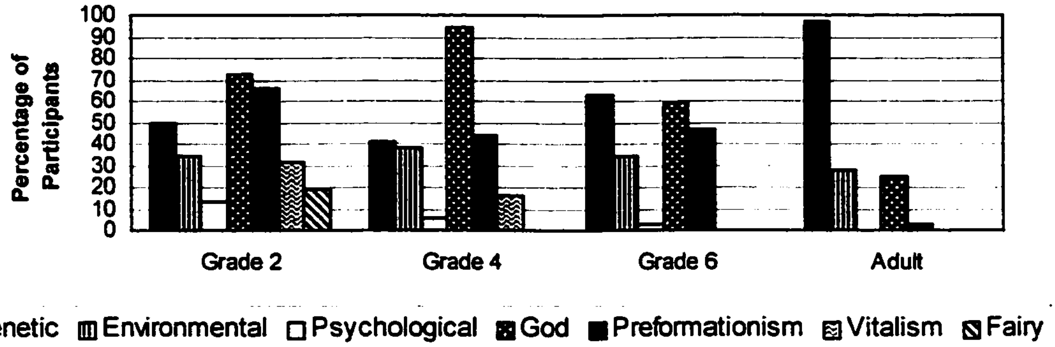


Figure 16
Percentage of Participants Per Age Group
Who Endorsed Each Explanation: Flower

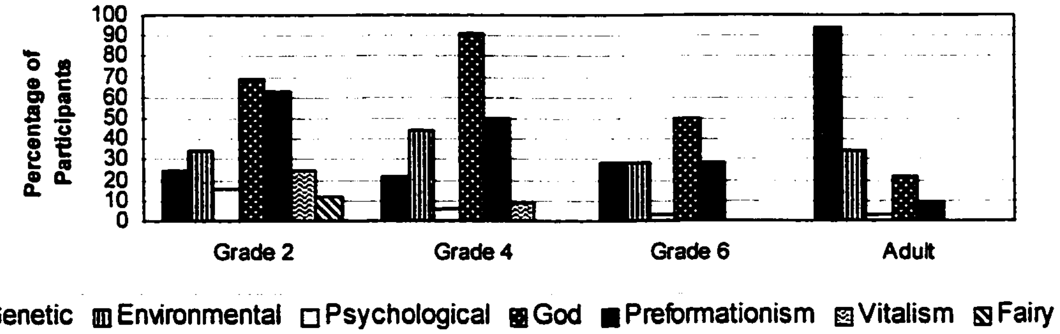
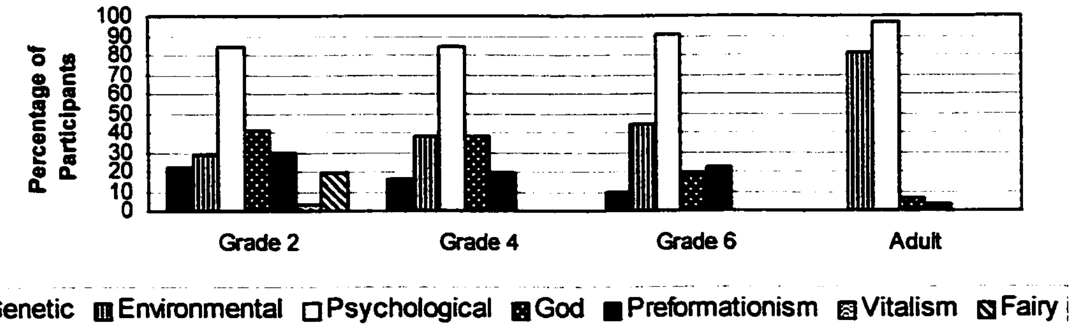


Figure 17
Percentage of Participants Per Age Group
Who Endorsed Each Explanation: Pail



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Appendix A

Interview Book and Pictures

Instructions to the Interviewer

This interview is comprised of 12 items--each composed of from one to several questions designed to get at children's understanding of inheritance of physical characteristics across 1 or 2 generations.

For each item, instructions to the interviewer are written in squared brackets. Do not read this information to the respondent.

Text that is to be read to the respondent is written in normal and bold font.

Statements written in normal font are meant to provide information to the respondent. Emphasize the statements that are underlined--either by slowing down your speech or changing your tone of voice.

Statements written in bold font are questions and thus require the interviewer to record a response.

Some questions are accompanied by pictures. Place relevant pictures in front of the respondent as you are reading the question (according to instructions that are embedded in the text in squared brackets)

Some questions are also accompanied by a 5-point scale. Place a copy of the scale in front of the respondent before reading these questions, asking them to indicate their choice by pointing and verbalizing the value they would choose.

Some questions are of the "Why do you think that..." variety. The goal is to get unambiguous responses to these questions. If the responses seem ambiguous--that is, if they cannot be categorized into any of the designated models, probe the respondent until they provide a codable answer. For example, vague responses can be followed up with "What do you mean by_______?" or "What do you think it is about ___________that causes_________?

"I don't know" or "I'm not sure" responses is to be followed by "What might help you know", "If you got this information, how would you answer this question now?", or "Why don't you know?"

If the respondent really does not seem to "know"--do not continue probing. Go on to the next question.

Item #1

Here's a dog. [point to large dog]

She has very small ears. This kind of dog usually doesn't have such small ears. Here's a puppy [point to puppy that is the same color as the large dog]. He is the same kind of dog as this one [point to large dog] but he is not her baby.

So, even though he is the same color as this dog [point to large dog again], he is not her baby

Notice that the picture of this puppy doesn't include ears.

[Q1a] When this puppy grows up, what size of ears do you think it will have. Do you think its ears will be...[read scale]

1	2	3	4	5
Very Small	**Somewhat Small**	**Average Size**	**Somewhat Large**	**Very Large**

or- **You're not sure.**

Just to help you remember, the adult dog's ears [point to large dog] are very small [place pointer at #1]--much smaller than normal for this kind of dog.

***[Q1b]** [If respondent chooses a number on the scale, ask] **Why do you think that it will have________________ears?**

If they say I'm not sure, ask] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

Here's another puppy. [point to puppy that is a different color than large dog]

He is the baby of this dog. [point to large dog again]

So even though he is a different color than this dog , he is her baby. Again, the ears of this dog was left out of the picture.

[Q1c] When this puppy grows up, what size of ears do you think it will have.

Do you thinks its ears will be...[read scale]

1	2	3	4	5
Very Small	**Somewhat Small**	**Average Size**	**Somewhat Large**	**Very Large**

or You're not sure.

***[Q1d]** [If respondent chooses a number on the scale, ask] **Why do you think that it will have_________________ears?**

[If respondent doesn't choose #1, ask] **Why won't it have very small ears like its mother?**

[If respondent says I'm not sure, ask] **What might help you know? If you had to guess based on the information you have, what would you choose?**

Can you show which puppy is the baby of this dog? [point to large dog] and **Can you show me which puppy is not the baby of this dog?** [point to large dog again]

[Q1e] For this puppy [point to first puppy], you said it will have ____________ [state size] ears when it grows up, and / but [choose one] than this puppy [point to second puppy] will have ______________ [state size] ears when it grows up.

Why do you think that this puppy [point to first puppy] **will have smaller / larger / same size ears** [choose one size] **than that puppy** [point to second puppy]**?**

Item #2

Here's a horse. [point to large horse]

She has a very large heart. This kind of horse usually doesn't have such a large heart.

Here's a colt [point to colt that is the same color as the large horse].

He is the same kind of horse as this horse [point to large horse], but he's not her baby.

So, even though he is the same color as this horse [point to large horse again], he is not her baby.

[Q2a] When this colt grows up, what size of heart do you think it will have? Do you think its heart will be...[read scale]

1	2	3	4	5
Very Small	**Somewhat Small**	**Average Size**	**Somewhat Large**	**Very Large**

or **You're not sure**

Just to help you remember, the adult horse's heart [point to adult horse] is very large [place point at # 5]--much larger than normal for this kind of horse.

***[Q2b]** [If respondent chooses a number on the scale, ask] **Why do you think that it will have a______________heart?**

[If respondent says I'm not sure, ask] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

Here's another colt [point to colt that is a different color than the adult horse].

He is the baby of this horse. [point to large horse again].

So even though he is a different color than this horse, he is her baby.

[Q2c] When this colt grows up, what size of heart do you think it will have? Do you think its heart will be...[read scale]

1	2	3	4	5
Very Small	**Somewhat Small**	**Average Size**	**Somewhat Large**	**Very Large**

or **You're not sure**

***[Q2d]** [If respondent chooses a number on the scale, ask] **Why do you think that it will have a_____________heart?**

[If respondent doesn't choose #5, ask] **Why won't it have a very large heart like its mother?**

[If respondent says I'm not sure, ask] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

Can you show me which colt is the baby of this horse? [point to large horse] and **Can you show me which colt is not the baby of this horse?**[point to large horse]

For this colt [point to first colt], you said it will have a___________[state size] heart when it grows up, and / but [choose one]that this colt [point to second colt] will have a______________ [state size] heart when it grows up.

[Q2e] Why do you think that this colt [point to first colt] **will have a smaller / larger / same size heart** [choose one size] **than that colt** [point to second colt]**?**

Item #3

Some people look a lot like each other and some people look very different from each other. I want to know whether you think people look like their parents or their friends. For example, when you look at peoples' faces, I want to know whether you think that people look like their parents or their friends. I'm not talking about things like style of clothes or hair.

[Q3a] Using this scale, do you think people look... [read scale]

1	2	3	4	5
Much more like their friends	**A little more like their friends**	**Equally like their parents & friends**	**A little more like their parents**	**Much more like their parents**

or **You're not sure.**

*__[Q3b]__ [If respondent chooses a number on the scale, ask] **What do you think causes people to look more like / same as** [choose one] **their parents / friends** [choose one] **than their parents / friends** [choose one]**?**

[If respondents say I'm not sure, ask] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

Now, I want to know whether you think people look like their parents or like their grandparents.

[Q3c] Using this scale, do you think people look [read scale]

1	2	3	4	5
Much more like their grandparents	**A little more like their grandparents**	**Equally like their parents & grandparents**	**A little more like their parents**	**Much more like their parents**

or **You're not sure.**

***[Q3d]** [If respondent chooses a number on the scale, ask] **What do you think causes people to look more like / same as** [choose one] **their parents / grandparents** [choose one] **than their parents / grandparents** [choose one]**?**

[If they say I'm not sure, ask] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

Item#4

Here is a baby girl and here are both of her parents. Notice that her parents are very short. She doesn't live with her parents. Instead, she grows up living with this couple. Notice that this couple is very tall.

[Q4a] When this baby girl grows up, how tall do you think she will be. Do you think she will be... [read scale]

1	2	3	4	5
Very Short like her parents	**Somewhat Short**	**Average Height**	**Somewhat Tall**	**Very Tall** like this couple

or **You're not sure.**

***[Q4b]** [If respondent chooses a number on the scale, ask] **Why do you think that the baby will be______________________when she grows up?**

[If respondent doesn't choose #1, ask] **Why don't you think that the baby will be very short like her parents when she grows up?**

[If respondent doesn't choose #5, ask] **Why don't you think that the baby will be very tall like the couple lives with when she grows up?**

[If respondent says I'm not sure, ask] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

Can you show me which couple are the baby's parents?

Can you show me which couple the baby grew up with?

Item #5

Here is Mr. and Mrs Jones. They work in a paint factory.

Their job caused their hands to be permanently stained with a blue color.

So now, their hands are blue instead of their normal skin color

They are about to have a baby.

[Q5a] When they baby is born, what color do you think its hands will be? Do you think its hands will be ....

a. blue

b. skin-colored

c. blue or skin-colored

d. not blue or skin colored but a different color instead

e. You're not sure

***[Q5b]** [Responses a, b, c will be followed by] **Why do you think that it will be born with__________ hands?**

[If respondent doesn't choose blue, ask] **Why won't it be born with blue hands?**

[Response d will be followed by] **What color will they be?** and **Why?**

[Response e will be followed by] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

Item #6

Here is Mr. and Mrs. Smith

Mrs. Smith has blue eyes and Mr. Smith has brown eyes.

They have a son.

[Q6a] What color do you think his eyes are? Do you think his eyes are

a. brown

b. blue

c. brown or blue

d. not brown or blue but a different color instead

e. you're not sure

***[Q6b]** [Responses a, b, and c will be followed with **Why do you think that his eyes are_________?]**

[Response d will be followed with] **What color do you think his eyes are** and **Why?**

[Response e will be followed with] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

They also have a daughter.

[Q6c] What color do you think her eyes are? Do you think her eyes are

a. brown

b. blue

c. brown or blue

d. not brown or blue but a different color instead

e. You're not sure

***[Q6d]** [Responses a, b, and c will be followed with **Why do you think that her eyes are ________?]**

[Response d will be followed with] **What color do you think her eyes are?** and **Why?**

[Response e will be followed with] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

If respondents choose different answers for questions 6a and 6c, ask **Why do you think that the son's eye color will be ____________but that the daughter's eye color will be______?**

Here is Mr. and Mrs. Blake.

Mrs. Blake has brown eyes and Mr. Blake has blue eyes

They have a son.

[Q6e] What color do you think his eyes are? Do you think his eyes are

a. brown

b. blue

c. brown or blue

d. not brown or blue but a different color instead

e. You're not sure

***[Q6f]** [Responses a, b, and c will be followed with **Why do you think that his eyes are _________?**]

[Response d will be followed with] **What color do you think his eyes are?** and **Why?**

[Response e will be followed with] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

They also have a daughter.

[Q6g] What color do you think her eyes are? Do you think her eyes are

a. brown

b. blue

c. brown or blue

d. not brown or blue but a different color instead

e. You're not sure

***[Q6h]** [Responses a, b, and c will be followed with **Why do you think that his eyes are _________?**]

[Response d will be followed with] **What color do you think her eyes are?** and **Why?**

[Response e will be followed with] **What might help you know?** and **If you had to guess based on the information you have, what would you choose?**

If respondents choose different answers for questions 6e and 6g, ask **Why do you think that the son's eye color will be ____________but that the daughter's eye color will be______?**

Item #7

Here is a puppy.

This puppy happened to be born a brown color, but sometimes this kind of puppy is born a different color, like black or tan.

***[Q7] Why do you think it is that this puppy is brown instead of a different color? What do you think caused this puppy to be brown?**

I'm going to read some ideas for why the puppy is brown. I want you to tell me what you think of them using this scale [show and read scale]

-If the idea sounds silly to you, choose #1 (very silly) or #2 (pretty silly)
-If the idea sounds good to you, choose #4 (pretty good) or #5 (very good)
-If the idea sounds partly silly and partly good, choose #3 (not silly and not good)
-You should also choose #3 if you don't know if the idea is silly or good
-After you choose a number, I will ask you to explain why you chose the number
-Do you have any questions?
-Here is the first idea.

[Q7a] Maybe it was a brown puppy right from the beginning when it was in its mother's tummy. Even when it was so tiny that you couldn't see it, it was a brown puppy [Preformationist]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q7b] Maybe the puppy was brown because a fairy sprinkled brown fairy dust on it's parents before he was born [Fantasy]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q7c] Maybe the puppy was born brown because the person who owned the puppy's mother and father wanted brown puppies [Psychological]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q7d] Maybe something around the puppy, either before or after it was born, caused it to be brown [Environment]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q7e] Maybe the puppy's skin wanted to be covered with brown fur [Vitalism]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q7f] Maybe the puppy got tiny things from its parents and these things contained instructions for the puppy to be brown [Genetic]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q7g] Maybe God chose brown for the puppy [Theological]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

Item #8

Here is a flower.

This flower happened to be pink when it bloomed, but sometimes this type of flower blooms into a different color, like yellow and red.

***[Q8a] Why do you think that this flower is pink instead of a different color? What do you think caused this flower to be pink?**

I'm going to read some ideas for why the flower is pink. I want you to tell me what you think of them using this scale [show and read scale]

[Q8a] Maybe it was a pink flower right from the beginning when it was inside the seed. Even when it was so tiny inside the seed that you couldn't see it, it was a pink flower. [Preformationist]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q8b] Maybe the flower was pink because a fairy sprinkled pink fairy dust on it before it bloomed [Fantasy]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q8c] Maybe the flower bloomed pink because the gardener who planted it wanted it to bloom pink [Psychological]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q8d] Maybe something around the flower, either before or after it bloomed, caused it to be pink [Environment]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q8e] Maybe the petals of the flower wanted to be pink [Vitalism]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q8f] Maybe the flower got tiny things, from its parents, and these things contained instructions for the flower to be pink [Genetic]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q8g] Maybe God chose pink for the flower [Theological]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

Item #9

Here is a metal pail.

This pail happens to be red, but sometimes this kind of pail can be a different color, like blue or green.

***[Q11] Why do you think this pail is red instead of a different color? What do you think caused this pail to be red?**

I'm going to read some ideas for why the pail is read. I want you to tell me what you think of them using this scale [show and read scale]

[Q9a] Maybe it was a red pail right from the beginning. Even when the metal pieces that make it up were so tiny that you wouldn't be able to see them, it was a red pail. [Preformationist]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q9b] Maybe the pail was red because a fairy sprinkled red fairy dust on it while it was being made [Fantasy]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q9c] Maybe the pail was red because the person making the pail wanted it to be red [Psychological]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q9d] Maybe something around the pail caused it to be red [Environmental]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q9e] Maybe the pail wanted to be red [Vitalism]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q9f] Maybe the pail has tiny things, and these things contain instructions for the pail to be red [Genetic]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

[Q9g] Maybe God chose red for the pail [Theological]

1	2	3	4	5
Very Silly	**Pretty Silly**	**Not Silly & Not Good**	**Pretty Good**	**Very Good**

Why do you think that this answer is_______________?

Item #10

Imagine that you are an explorer who has landed on an island in the South Pacific. First, you see a bird called a shreeble. It is female and blue. [point to picture of bird]

[Q10a] After seeing this one single female Shreeble, about how many of the other female shreebles on the island would you guess are also blue? [point to pie chart]

Would you guess that...

a. none of the other female shreebles on the island are blue
b. less than half
c. about half
d. more than half, or
e. all of the other female shreebles on the island are blue?

[If respondent has trouble making a guess, cue them to use their world knowledge about birds and their coloring to make a guess]

[Q10b] Why did you guess this amount?

Next, you see a man who is a native of the island. He has a very heavy build. [point to picture of heavy man]

[Q10c] After seeing this one single man, about how many of the other men on the island would you guess also have a heavy build? Would you guess that

a. none of the other men on the island have a heavy build

b. less than half

c. about half

d. more than half, or

e. all of the other men on the island have heavy builds?

[If respondent has trouble making a guess, cue them to use their world knowledge about people and their body types to make a guess]

[Q10d] Why did you guess this amount?

Next, you see a scientist who is burning a mineral called *Cartium*. When she burns it, it gives off bright purple smoke.

[Q10e] After seeing this one piece of Cartium being burned, how many of the other pieces of Cartium on the island would you guess would give off bright purple smoke when burned? Would you guess.....[point to accompanying pie chart]

a. none of the other pieces of Cartium would give off bright purple smoke when burned

b. less than half

c. about half

d. more than half, or

e. all of the other pieces of Cartium would give off bright purple smoke when burned

[If respondent has trouble making a guess, cue them to use their world knowledge about minerals or rocks to make a guess]

[Q10f] Why did you guess this amount?

Item #11

Many people study the environment--which includes a lot of different kinds of things around us. [Point to appropriate picture as you read the following list of environmental factors] The environment includes the different kinds of people around us and how they make us feel. It includes different things around us, like the weather, the type of foods available to eat, the quality of air and water, and the amount of noise. People who study the environment can even look at the environment that surrounds a baby in its mother before it is born. So, all these kinds of things are part of the environment.

[Q11a] Do you think that anything in the environment can affect how tall people grow up to be?

[If no, ask] **Why not?**

[If yes, present the following scale and ask] **What kinds of things in the environment can affect how tall people grow up to be?** and **How much do you think that the environment can affect how tall people grow up to be? Do you think the environment has....**[read scale]

1	2	3	4
Little Effect	**Some Effect**	**Much Effect**	**Complete Effect**

[Q11b] Why did you choose___________effect?

[Q11c] Are there other things that I didn't mention that could affect how tall people grow up to be? [If yes, ask] **What are they?**

[If all answers are environmental, ask] **Are there other things that are not part of the environment that could affect how tall people grow up to be?** [If yes, ask] **What are they?** [If no and they also chose #1, #2, or #3 for Q11a, ask] **Why didn't you say that the environment has a complete effect on how tall people grow up to be?**

[Q11d] Do you think that anything in the environment can affect the number of arms people have when they're born? [If no, ask] **Why not?**

[If yes, present the following scale and ask] **What kinds of things in the environment can affect how many arms people have when they are born? How much do you think that the environment can affect the number of arms they have when they are born? Do you think the environment has....**[read scale]

1	2	3	4
Little Effect	**Some Effect**	**Much Effect**	**Complete Effect**

[Q11e] Why did you choose ________effect?

[Q11f] Are there other things that I didn't mention that could affect the number of arms people have when they are born? [If yes, ask] **What are they?**

[If all answers are environmental, ask] **Are there other things that are not part of the environment that could affect the number of arms people have when they're born?**

[If yes, ask] **What are they?**

[If no and they also chose #1, #2, or #3 for Q11d, ask] **Why didn't you say that the environment has a complete effect on the number of arms people have when they are born?**

[If respondent gives <u>different responses</u> to questions 11a and 11d read the following text and ask question 11g.]

You stated that the environment has____________________[specify level of effect] on how tall a person will be when they grow up, but that the environment has_____________ [specify level of effect] on the number of arms people have.

[Q11g Why do you think the environment has a greater effect on height number of arms [choose one] **than on height / number of arms** ? [choose one]

[If respondent says "no" to both Q11a and Q11d, ask] **Are there any characteristics that can be affected by the environment?**

Item #12

[Q12a] [If respondent does not mention "gene" for the entire interview, ask] **Have you ever heard of genes?** If they have mentioned "gene", continue to Q12b.

[Place card in front of subject with the word "gene" written on it and say,] I do not mean the kinds of jeans you wear, but the kind you might learn about in your science class.

[If respondent says *no*, do not continue with item #12.]
[If respondent says *yes*, ask the following questions.]

[Q12b] What do you think they do?

[Q12c] What kinds of things have genes?

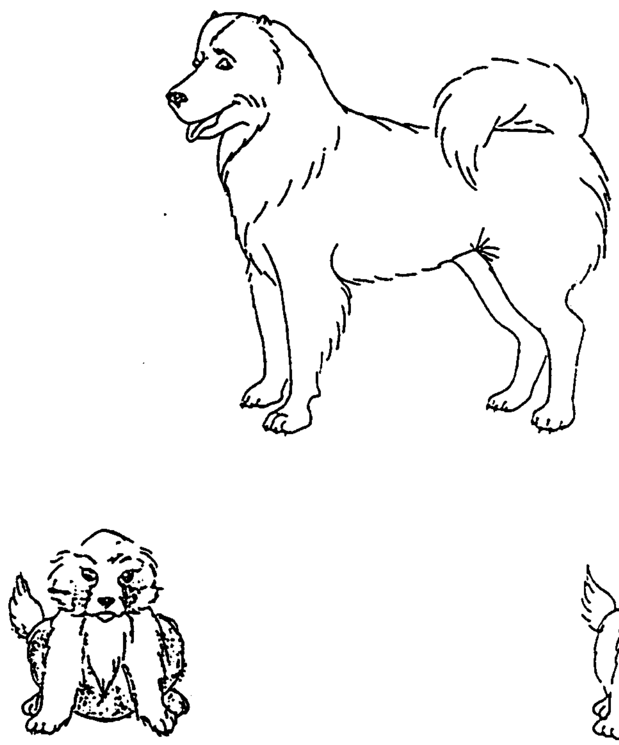
[If respondent does not mention "all living things", "people" "animals", and/or "plants" in Q12c, ask,] **Do people have genes?, Do animals have genes?, Do plants have genes?**

[Q12d] Where do we get our genes from? [If respondent only mentions the mother, ask] **Do we get genes from our father as well?**

[Q12e] Where are genes found?

[Q12f] Is it possible to see a gene? [If *yes*, **How?**, if no, Why not?]

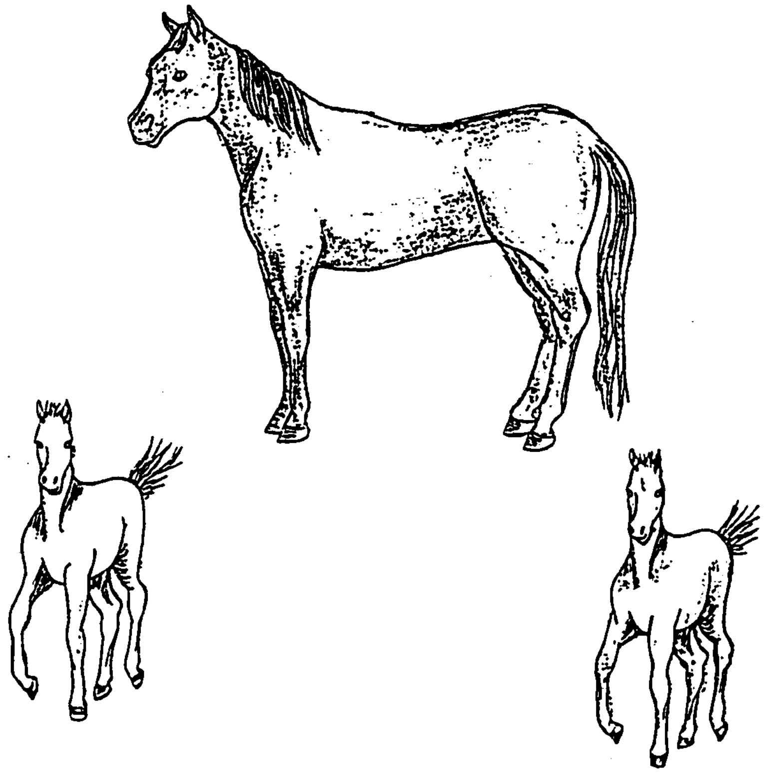
Figure A1: Picture and scale used for item 1.



1 . . . . . 2 . . . . . . 3 . . . . . . 4 5

Very Small	Somewhat Small	Averaged Sized	Somewhat Large	Very Large

Figure A2: Picture and scale used for item 2.



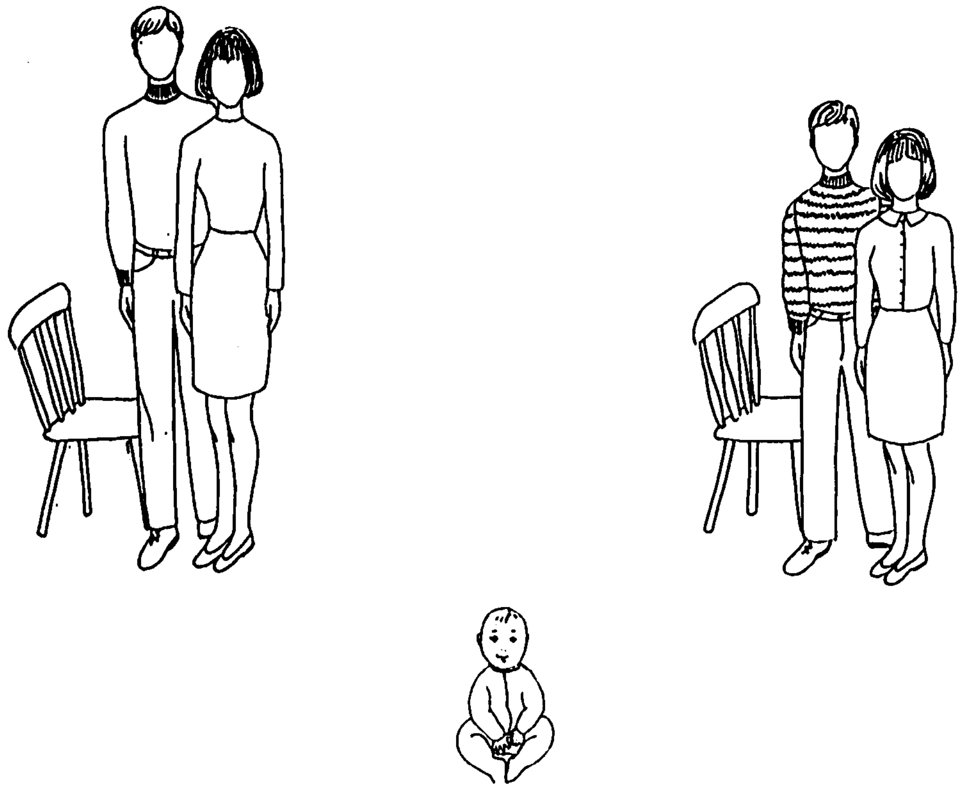
1	2	3	4	5
Very Small	Somewhat Small	Averaged Sized	Somewhat Large	Very Large

Figure A3: Scales used for item 3.

1	2	3	4	5
Much More Like Their Friends	A Little More Like Their Friends	Equally Like Their Parents & Friends	A Little More Like Their Parents	Much More Like Their Parents

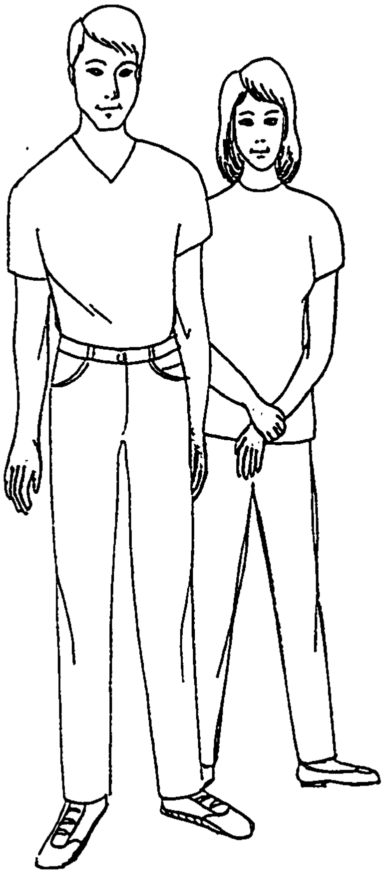
1	2	3	4	5
Much More Like Their Grandparents	A Little More Like Their Grandparents	Equally Like Their Parents & Grandparents	A Little More Like Their Parents	Much More Like Their Parents

Figure A4. Picture and scale used for Item 4.



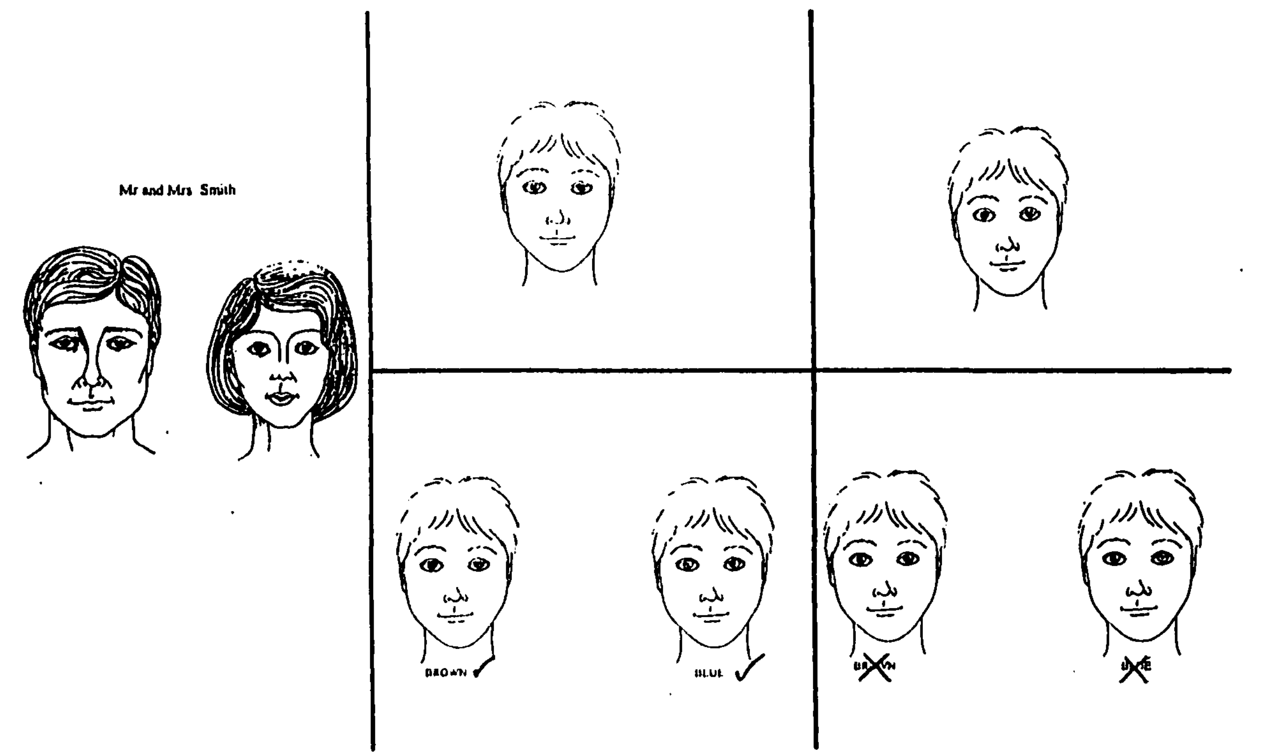
1	2	3	4	5
Very Short (like her parents)	**Somewhat Short**	**Average Height**	**Somewhat Tall**	**Very Tall (Like this couple)**

Figure A5: Picture and response options used for item 5.



a. Blue
b. Skin-colored
c. Blue or skin-colored
d. Not blue and not skin-colored but a different color
e. Not sure

Figure A6. Pictures and response options used for Item 6.

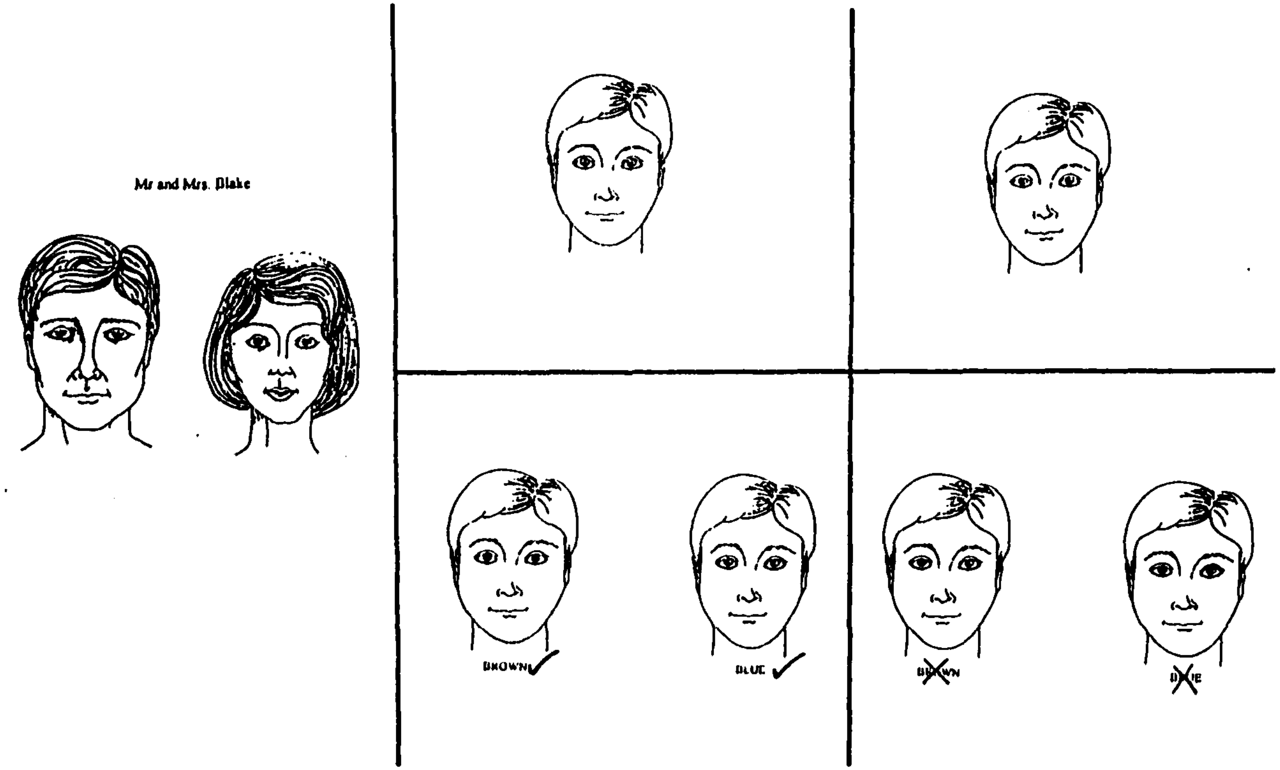


a. Brown b. Blue c. Brown or Blue d. Not Brown or Blue, but a different color e. Not Sure

Figure A6. Pictures and response options used for Item 6.

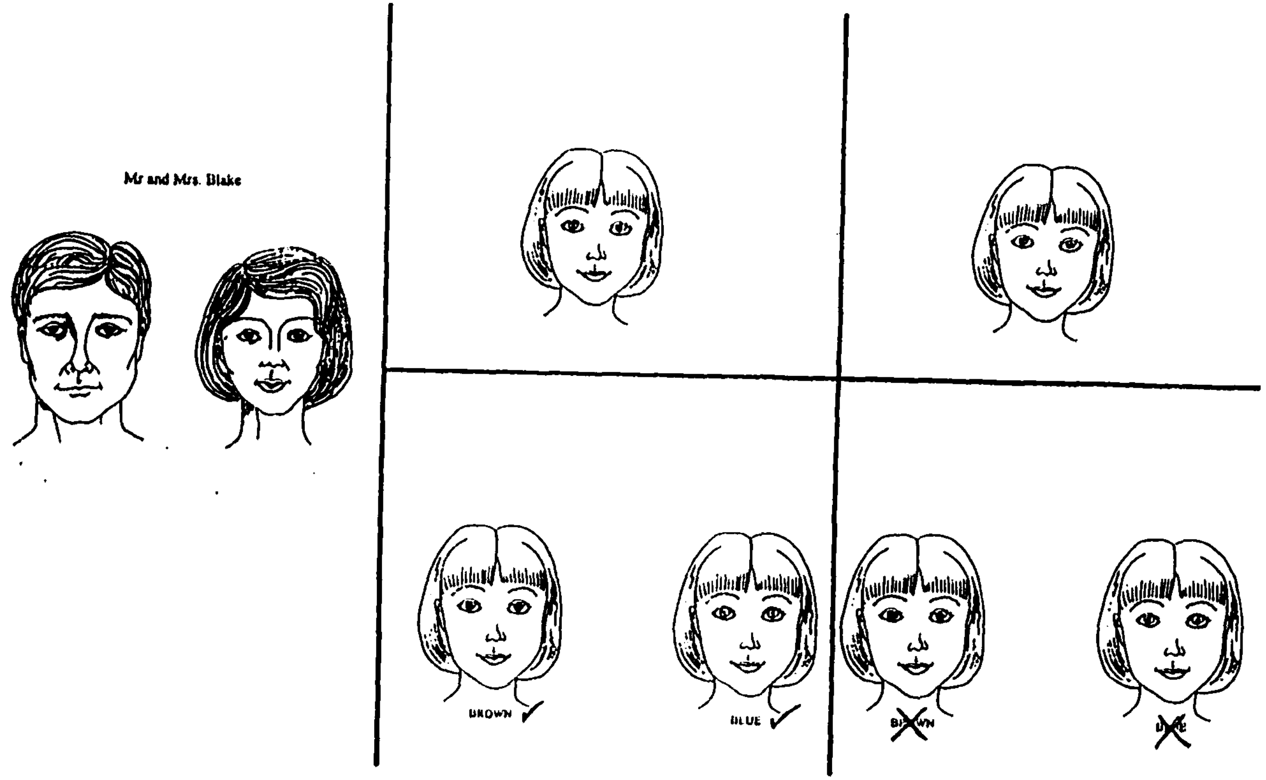
a. Brown b. Blue c. Brown or Blue d. Not Brown or Blue, but a different color e. Not Sure

<u>Figure A6.</u> Pictures and response options used for Item 6.



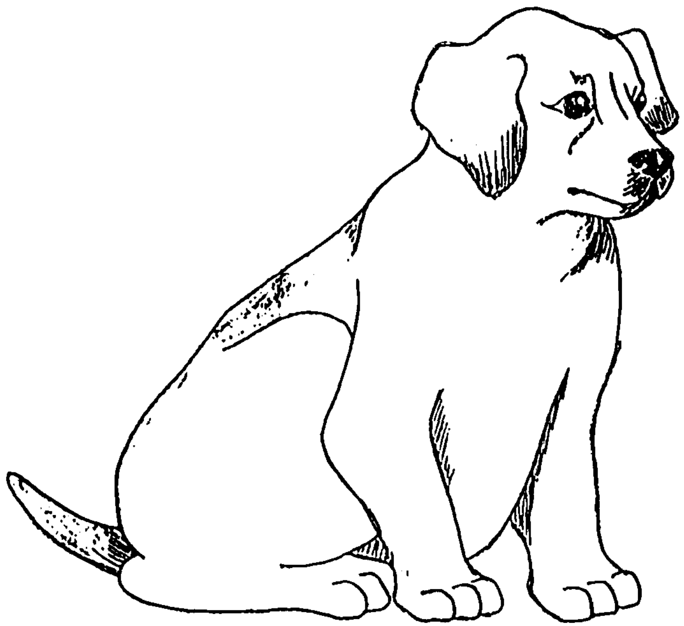
a. Brown **b. Blue** **c. Brown or Blue** **d. Not Brown or Blue, but a different color** **e. Not Sure**

Figure A6. Pictures and response options used for Item 6.



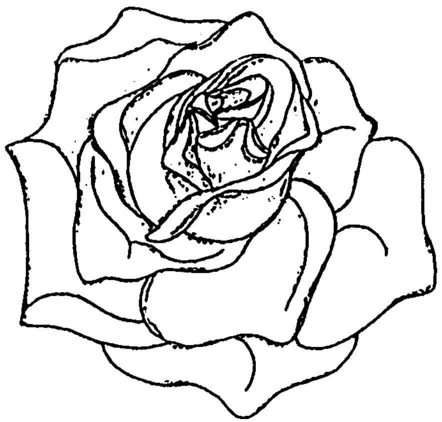
a. Brown **b. Blue** **c. Brown or Blue** **d. Not Brown or Blue, but a different color** **e. Not Sure**

Figure A7. Picture and response options used for Item 7.



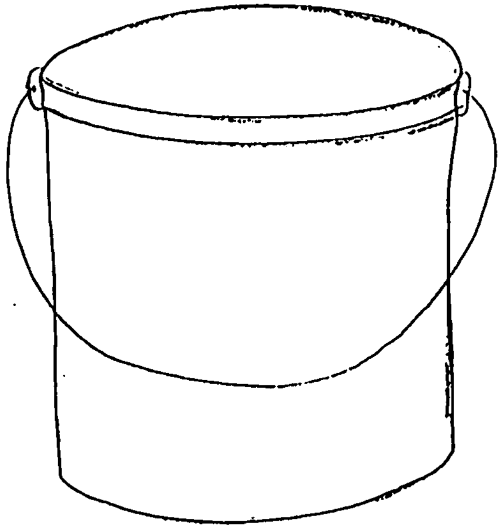
1. Very Silly **2. Pretty Silly** **3. Not Silly & Not Good** **4. Pretty Good** **5. Very Good**

Figure A8. Picture and response options used for Item 8.



1. Very Silly 2. Pretty Silly 3. Not Silly & Not Good 4. Pretty Good 5. Very Good

Figure A9. Picture and response options used for Item 9.



1. Very Silly **2. Pretty Silly** **3. Not Silly & Not Good** **4. Pretty Good** **5. Very Good**

Figure A10. Pictures and response options used for Item 10.

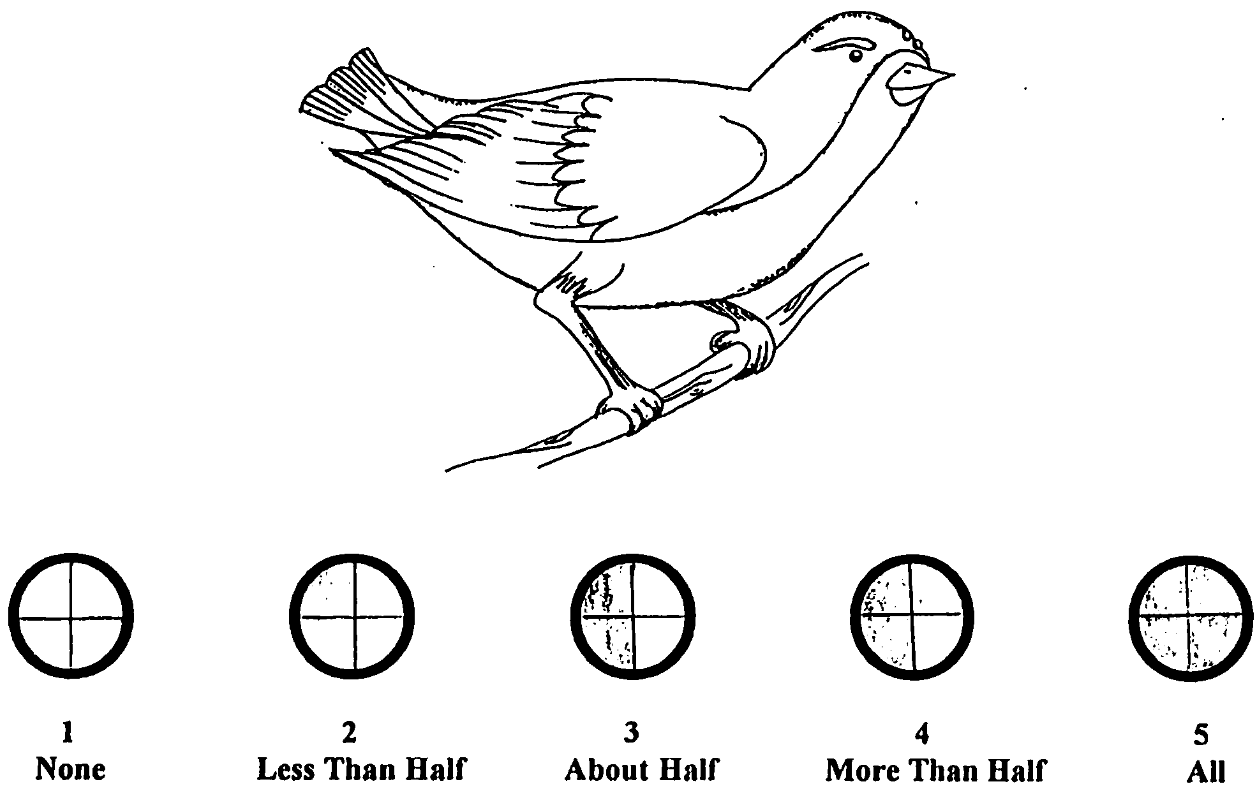


Figure A10. Pictures and response options used for Item 10.

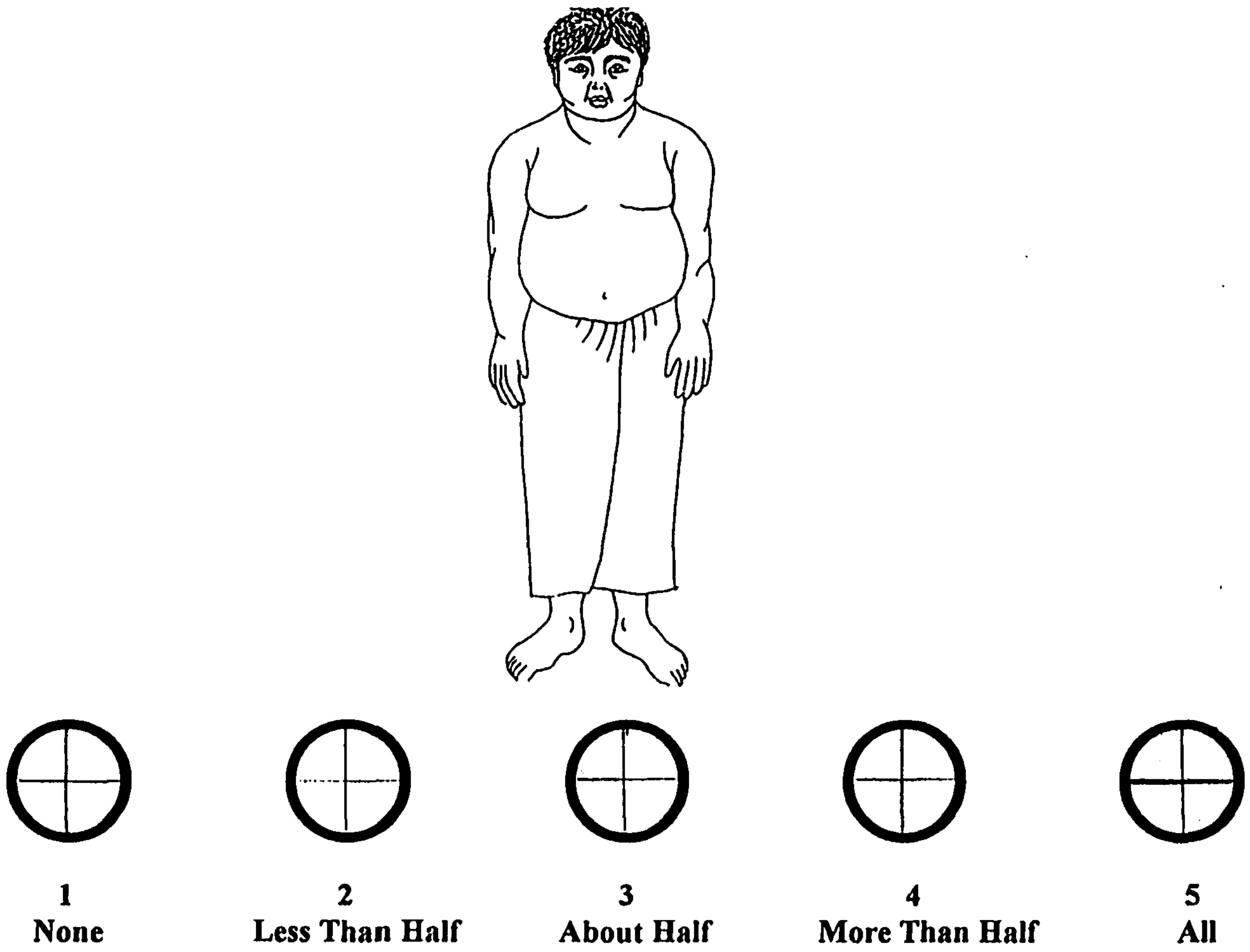


Figure A10. Pictures and response options used for Item 10.

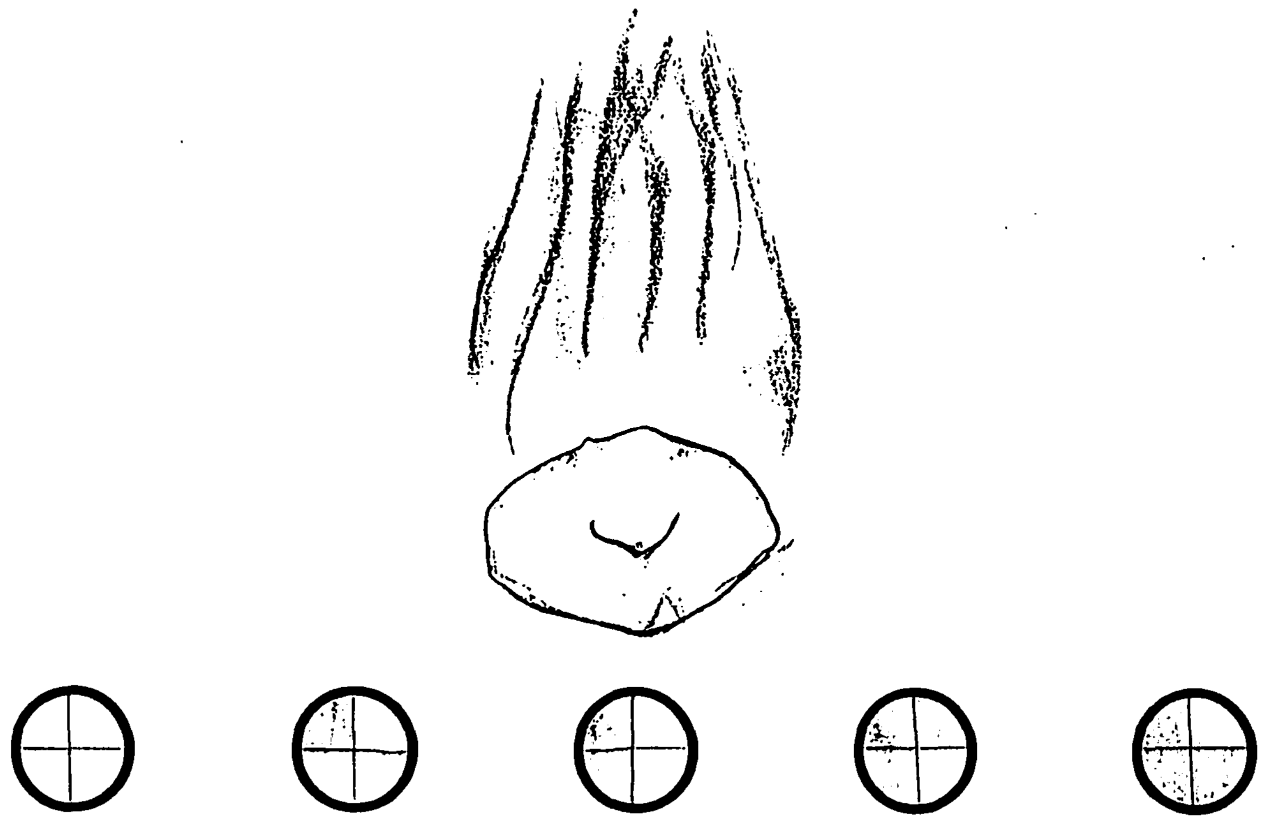
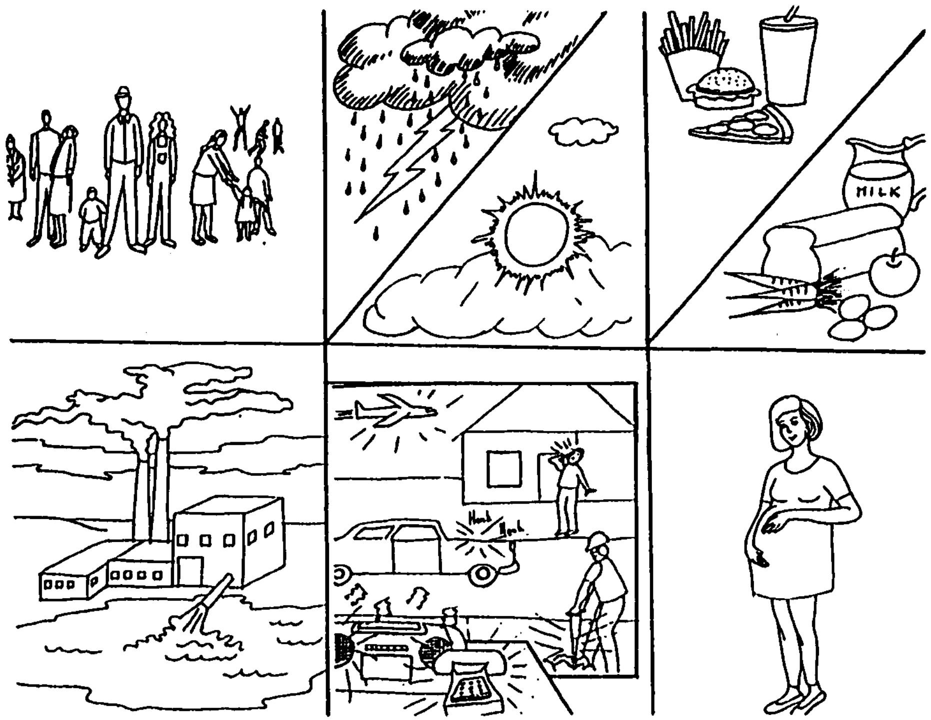


Figure A11. Picture and response scale used for Item 11.



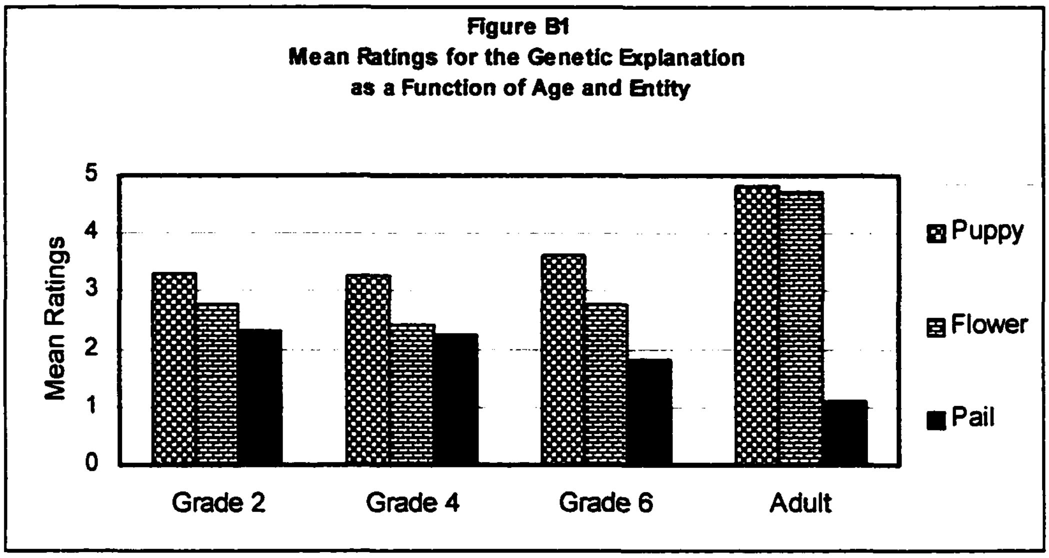
1	2	3	4
Little Effect	Some Effect	Much Effect	Complete Effect

<u>Figure A12.</u> Word presented in Item 12.

Gene

Appendix B

Mean Ratings on the Endorsement Task



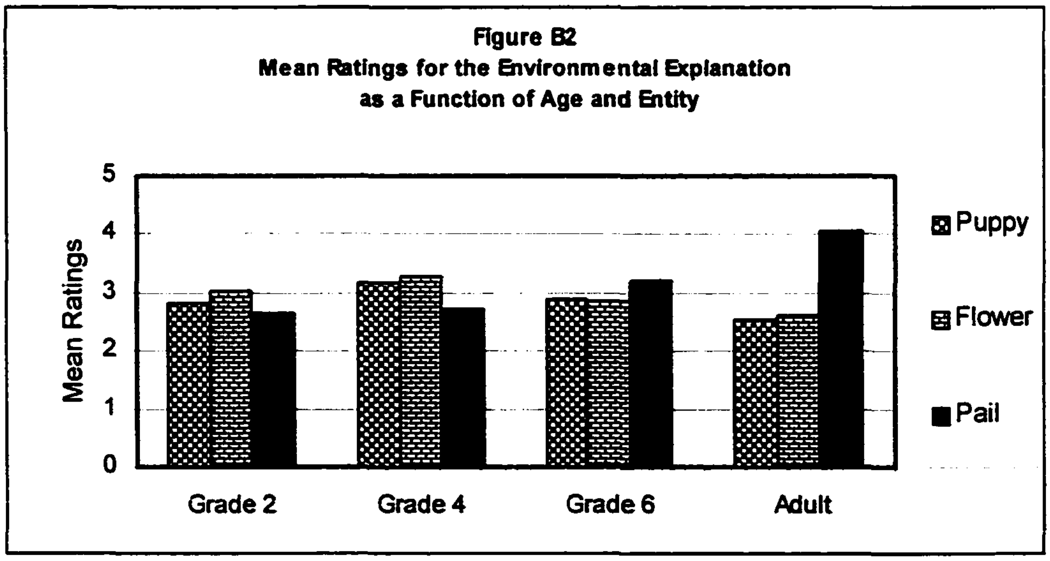


Figure B3
Mean Ratings for the Psychological Explanation
as a Function of Age and Entity

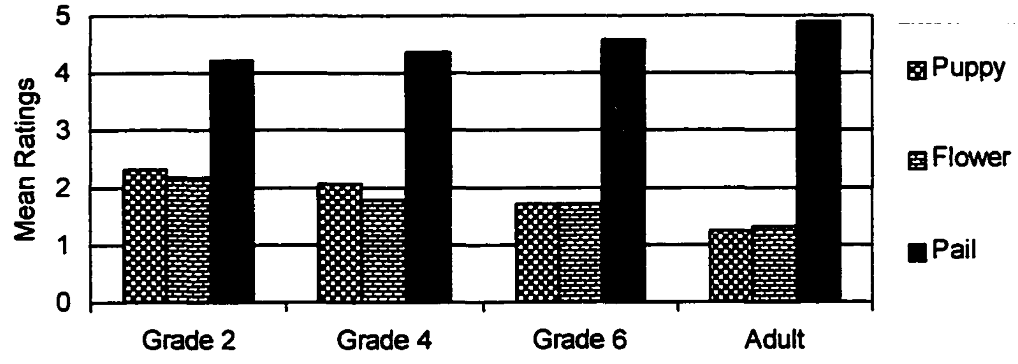


Figure B4
Mean Ratings for the Theological Explanation
as a Function of Age and Entity

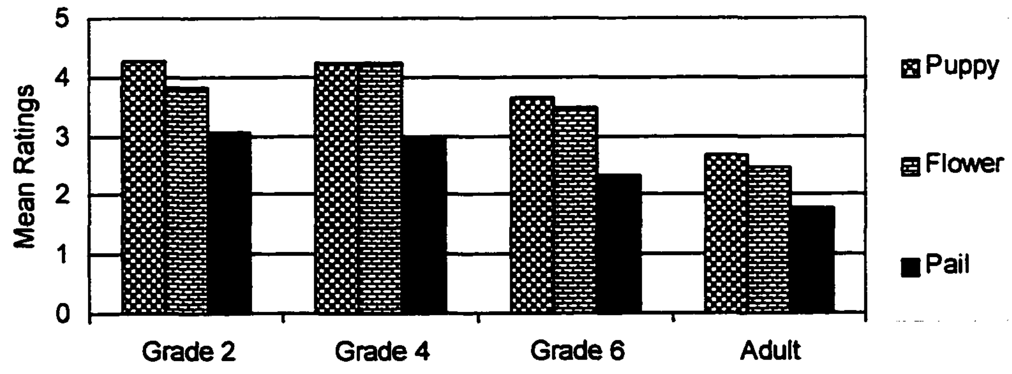


Figure B5
Means Ratings for the Preformationist Explanation
as a Function of Age and Entity

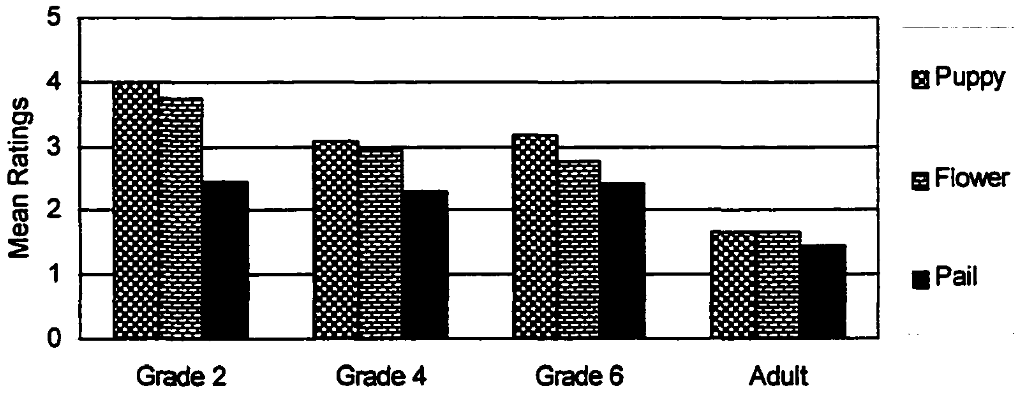
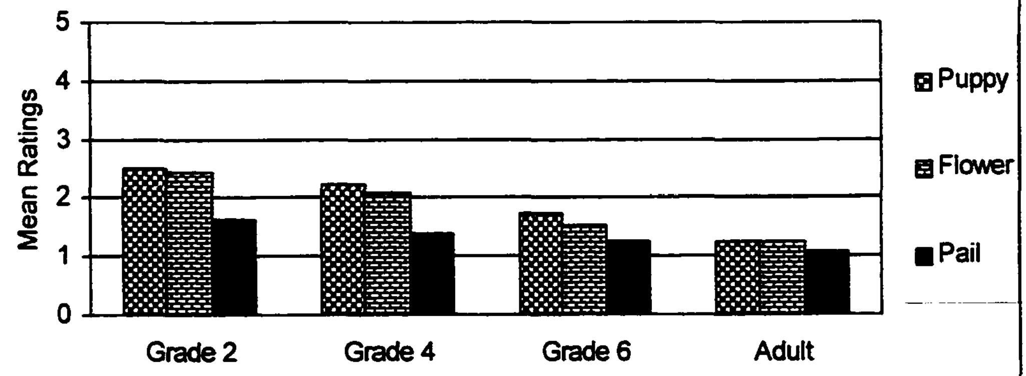


Figure B6
Mean Ratings for the Vitalistic Explanation
as a Function of Age and Entity



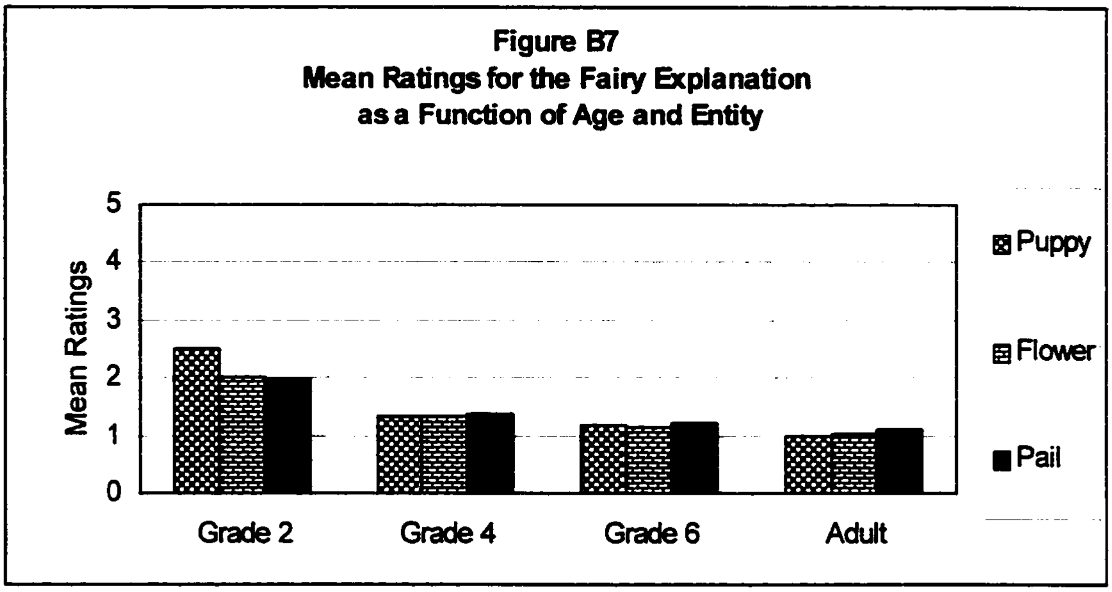


Figure B7
Mean Ratings for the Fairy Explanation
as a Function of Age and Entity
Mean Ratings
0
1
2
3
4
5
Grade 2
Grade 4
Grade 6
Adult
Puppy
Flower
Pail

Appendix C

Responses to Items 1 to 6

Presented in this section are participants' responses to items 1 to 6, including their choices and explanations for their choices. Age effects on choice (e.g., item 1a: chose option #1: Very Small Ears? Yes or No) were analyzed using Pearson chi-square tests ($\alpha = .05$). When significant effects were found, further Pearson chi-squares ($\alpha = .01$) were used to determine which age groups differed. Age effects on the number of different explanations generated in each item were also analyzed, using a one way analysis of variance ($\alpha = .05$), with age as the independent factor. Each item is discussed in turn.

Items 1 and 2: Species-ship, Kinship or Perceptual Information

Of interest in these two items (see Appendix A),was the type of information individuals rely on when making predictions about inheritance in traits: species-ship, kinship, or perceptual information. Other types of knowledge used in the decision process were also of interest. Participants' choices in these items are presented in Figures C-1 to C-4.

For the related infant, most participants thought that the offspring would be similar to its mother in terms of the unusual trait. With regard to the puppy, 81% of all participants' choices were on the small end of the scale, and for the horse, 83% of participants' choices were on the large end of the scale. The tendency to say that the offspring would be exactly like its mother in terms of the unusual trait varied with age, however, for both the puppy $\chi^2(3, N=128) = 20.27$, $p < .001$, and the horse, $\chi^2(3, N=128) = 13.97$, $p < .001$. Fewer adults than children thought that the puppy would have very small ears when it grew up, $\chi^2(1, \underline{N}=128) = 18.84$, $\underline{p} < .001$, and that the baby horse would have a very large heart, $\chi^2(1, \underline{N}=128) = 13.71$, $\underline{p} < .001$. In other words, many children expected the mother's trait to be replicated in the offspring whereas more adults expected some variation. Justifications were similar across the two items and across the three groups of children, but varied slightly between children and adults.

Almost all participants focused on kinship (average proportion = 95%), particularly the link between the infant and its mother. A few children also elaborated the nature of this relationship by providing specific biological connections. A genetic link was mentioned by 1 child in Grade 2, three children in Grade 4, and three children in Grade 6. Birth was referred to by three children in Grade 2 and two children in Grade 6; and a physiological link (e.g., blood, cells) was mentioned by four children in Grade 4 and eight children in Grade 6. Only 10% of children mentioned the father's contribution to the trait. Ninety-two percent of adults cited genes as the reason for why the infants would share the trait with its mother; 69% of these adults mentioned the father's contribution to the trait. Only 20% of all participants mentioned species-affiliation in their justifications, perhaps indicating that kinship overrides species-ship in making decisions about inheritance. Similarly, color of the animals rarely influenced predictions, even though participants were cued to consider this superficial feature Of the few who mentioned color in their justification, (11% of all participants; adults referred to color as often as children), many either said that it does not influence whether other features are passed from parent to offspring, or said that if the parent and infant share the trait of color, they may share other traits as well. These justifications are quite reasonable and indicate that all participants, including children, were not appearance-bound when making their decisions.

For the unrelated infants, predictions were somewhat variable across age groups, but most participants (87%) thought that the unrelated puppy would have either average ears, or small ears like the target. Most participants (89%) also thought that the horse would have either an average heart or a large heart like the target. In their justifications, 51 % of participants referred to kinship, (or rather lack thereof) which less than the proportion who mentioned this type of relationship for the related infant. Reference to species affiliation increased, however, with 49% of all individuals mentioning this type of link. Reference to species affiliation was most prevalent among individuals who thought that the infant would share the trait with the adult. Many mentioned that the infant and target belong to the same species, ignoring the fact that the trait was in fact unusual for the species. Only one child and only 34% of adults mentioned genes in their justifications, suggesting that genes are less salient when reasoning about traits at the species level than when reasoning about traits at the level of kinship. Again, few participants referred to other factors, such as color.

The number of different types of explanations individuals generated in items 1 and 2 increased with age; $F(3, 124) = 7.137$, $p < .001$ for item 1, and $F(3, 124) = 3.37$, $p < .05$ for item 2. Generally, adults included more ideas in their explanations than children, $F(1, 126) = 16.55$, $p < .01$ for item 1, and $F(1, 126) = 5.16$, $p < .05$ for item 2. Adults expressed an average of 3.47 and 3.06 ideas in items 1 and 2, respectively, whereas children generated 2.58 and 2.49 ideas. As a group, however, children provided a greater variety of ideas. Adults restricted their ideas to kinship, species-ship, genes, perceptual features and statistical reasoning. Unlike children, they never referred to behavioral factors (e.g., exercise could make a heart larger), God, physiological concepts (e.g., shared blood between parent and offspring), or the fact that the adult gave birth to its infant.

Item 3a: Social vs Biological Relationship

In this item, participants were asked whether they think people tend to look more like their friends or their parents (see Appendix A). The focus was on stable, physical features, and of interest was whether individuals, particularly children, believed these features could be influenced by psycho-social factors (e.g., friendship). Participants' responses to this item are presented in Figure C-5.

Most participants indicated that people tend to look more like their parents than their friends, but proportions varied across age groups, $\chi^2(3, N=128) = 12.91$, $p < .005$. Children in Grade 2 were more likely than the other three groups to accept the possibility that people can look more or equally likely their friends than parents $\chi^2(1, N=128) = 11.10$, $p < .001$. Eleven children in all grades thought that people look equally like their parents and friends, but justifications were mostly anecdotal. Four children in Grade 2 believed that people look more like their friends than their family. Three of these children stated that people often choose friends that look like themselves, and one child indicated that growing up in a different time and place make people look less like their parents and more like their friends. Social-psychological factors (i.e., intentions) were never mentioned as possible causes for similarity between individuals.

Among the individuals who thought that people look more like their parents than friends, all adults and 15% of children stated that people share more genes with their parents than their friends. Some children (average proportion of all children = 27%) also referred to the fact that children are born from their parents, and five children in Grade 6 indicated that parents and their offspring share the same blood. Most of the remaining children simply stated that people are related to their parents, and not their friends. Thirteen children in Grade 2, and three children in each of Grades 4 and 6 did not know of the reasons underlying the greater similarity between parents and offspring, but often gave anecdotal evidence supporting this belief. Only a few individuals across all age groups mentioned possible environmental reasons for why people look more like their parents (similar diet and exercise habits). This small number may reflect their recognition that stable physical features are not greatly influenced by environmental differences.

Overall, participants generated an average of 2.06 ideas when responding to this question, a number that did not differ across age groups.

Item 3b: Generational Factors

In this item, participants were asked whether they think people tend to look more like their parents or grandparents (see Appendix A). Of interest was whether decisions would be affected by differences in the degree of biological relationship between people and their kin, and whether social factors would also be considered. Participants' responses to this item are presented in Figure C-6.

Decisions varied with age group, both in terms of the proportion of participants who said that people look equally like their parents and grandparents $\chi^2(3, \underline{N}=128) = 16.27$, $\underline{p} < .001$, and in terms of the proportion who said that people look more like their parents than their grandparents, $\chi^2(3, \underline{N}=128) = 17.82$, $\underline{p} < .001$. Children's predictions were similar to one another, but differed from adults. More children than adults thought that people look equally like parents and grandparents, $\chi^2(1, N=128) = 14.40$, $p < .001$, and fewer children than adults thought that people look more like their parents than their grandparents, $\chi^2(1, N=128) = 16.73$, $p < .001$. Eighty-one percent of adults mentioned that over the generations, people share proportionally less genes with their ancestors than their parents. Another four adults said that genes can mutate over the generations. Only three adults thought that people look equally like their parents and grandparents, reasons being that genes are the same across generations.

Children were more divided in their opinions; the proportion of children who said that people look more like their parents than their grandparents was similar to the proportion who said that people look equally like their parents and grandparents (See Figure C-6). Of the children who thought that people tend to look more like their parents, half stated that people are more closely related to their parents than their grandparents. Another two children in each grade also said that people are born from their parents, not their grandparents. Three children in Grade 2 thought that shared environment is responsible for greater physical similarity to parents.

Of the children in Grade 2 who believed that people look equally like their parents and grandparents, half mentioned that grandparents gave birth to our parents, who in turn gave birth to us. The other half were not sure of the reason, but some gave anecdotes supporting their belief. Children in Grades 4 and 6 who held this opinion generated justifications that were somewhat similar to each other. About 82% of these children emphasized the fact that grandparents give birth to parents. Other children specifically mentioned that things get passed down from our grandparents to our parents, and from our parents to us, and that these things are responsible for the equal similarity. Four children in Grade 4 were vague about what these things were, two mentioned genes. Four children in Grade 6 referred to cells and blood and an additional three children alluded to genes. Generally, these children understand that there is some sort of biological link between people and their grandparents, but did not recognize that the amount of shared biological material (i.e., genes, blood, cells) decreases across generations.

Only six children in Grade 2 and two children in Grade 4 said that people tend to look more like their grandparents than parents. Of these eight children, six were not sure why, one child gave anecdotal evidence, and only child thought that people share more genes with their grandparents.

Item 4: Adoptive vs Biological Parents

This item was designed to investigate whether biological connections take precedence over possible environmental influences, including psycho-social influences, when participants reason about inheritance of physical traits. If so, then participants should predict that children are more likely to resemble their biological parents than their adoptive parents. Participants' predictions are presented in Figure C-7.

Predictions varied significantly across age-levels, $\chi^2(3, N=128) = 16.09, p < .001$, as did the number of ideas included in justifications, $F(3, 124) = 5.30, p < .005$. More adults (97%) than children (average proportion = 61%) said that the baby would grow up to be short like her parents, $\chi^2(1, N=128) = 13.81, p < .001$. About 87% of these adults mentioned the biological relationship between the biological parents and the child, explaining that genes are passed down from the biological parents determine the baby's height. Fifty percent also claimed that the environment has no effect on ones height. Ninety percent of the children who thought that the baby would grow up to be short like her biological parents mentioned a biological link between the child and her biological parents; 76% of these children emphasized that the baby was born from the short couple, not the tall couple. Four children in each of Grades 4 and 6 specified that genes are passed from biological parents and not from adoptive parents. An additional two children from each grade thought that the baby will grow up to be short because she shares blood with her biological parents. Only 16% of the children who thought the baby would grow up to be short explicitly said that the environment plays no role in determining height.

A number of children in each grade (average proportion = 23%) and one adult predicted that the baby would grow up to be averaged height. The adult and 50% of the children provided statistical reasons. The adult's response reflected an understanding of the concept of regression to the mean, specifically that when parents have a trait that is extreme in value, the offspring will be less extreme in that trait. Children stated that offspring often differ from their parents in how traits are expressed or that average height is most common in people. Environmental influences on height, such as diet, were mentioned by 38% of children. None of the children suggested that psych-social factors could affect growth processes. The remainder of the children who thought the baby would be average in height did not know why. A few children predicted that the baby would grow up to be tall. Seventy-three percent of these children cited possible environmental reasons, such as diet. Again, psycho-social influences were not mentioned.

A few children also provided statistical reasons, particularly variation. Interestingly, many participants provided responses that were not in line with their responses to questions in item 11. Recall that 87% of all participants stated that they thought that height is affected by the environment. Forty eight percent of the children who believed that the environment plays a role did not mention the environment in their justifications in item 4, and another 13% gave justifications that contradicted the answers they provided in item 11. More surprisingly, of the adults who said in item 11 that the environment affects height, 50% contradicted themselves in item 4 by saying that the environment has no effect on height, another 13% did not include environmental reasons in their justifications. Only 34% of adults and 29% of children gave consistent answers to questions in both items. It is possible that individuals who failed to mention environmental factors in item 4 assumed that the environment would be similar for the biological and adoptive parents, or perhaps they needed to be cued to consider environmental factors. It is not clear why so many individuals, especially adults, contradicted themselves, however.

Item 5 Transmission of Acquired Traits

Item 5 was designed to determine whether participants believe that acquired traits are transmittable from parent to offspring before birth. If not, participants should predict that a baby born to parents who have blue-dyed hands would be born with normal, skin-toned hands. Predictions varied with age, $\chi^2(3, N=128) = 20.03$, $p < .001$. Adults were more likely than children in Grade 6 to say that the baby would be born with skin-toned hands, $\chi^2(1, N=128) = 7.86$, $p < .005$, who in turn were more likely to make this prediction than children in Grades 2 and 4, $\chi^2(1, N=128) = 3.84$, $p = .05$ (see Figure C-8).

Although all age groups were similar in terms of the number of ideas generated in their justifications (average number = 1.6 ideas), the nature of the reasons differed between children and adults.

None of the adults indicated that offspring would inherit dyed hands from their parents; 72% explained that the dye would not affect the genes that determine hand color. Another 28% stated that in order to have blue hands, one would have to be directly exposed to the dye (e.g., work in a paint factory). The majority of children (mean of 65%) also believed that offspring do not inherit this acquired trait from their parents. The types of responses generated by children in all three grades were somewhat similar. An average of 38% of children mentioned that blue hands can only be acquired through direct exposure to paint or dye. An additional four children per grade asserted that the baby would be protected inside its mother before its birth. Three children in Grade 6 stated that the dye would not affect the genes and therefore would not be passed on to the offspring. Most of the remaining children who predicted that the baby would have skin-toned hands simply said that people tend to be born with normal skin colored hands

Of the eight children who thought that it was possible that the baby could be born with blue hands, half suggested that the dye could soak through the mother's skin, enter her bloodstream, and affect the baby while in the womb. One thought that exposure to the paint would cause the baby to get a disease that would give her blue hands. The remaining three were not sure why the baby would have blue hands. Only three children in Grade 2 and one child in Grade 6 gave responses that indicated a Larmarkian view of inheritance. These children believed that the baby would have blue hands at birth simply because the parents had blue hands.

Of the children who predicted that the baby could be born with either blue or skin toned hands, over half (56%) said it depended on whether the paint could soak through the parents skin and contact the baby. Twenty-five percent said it depended on how long the baby is exposed to the paint. The remainder were not sure why the baby could be born with either color of hands.

Item 6: Paternal and Maternal Contribution to Traits

This item was intended to assess participants' views on the contribution both parents make to a trait known by scientists to be determined primarily by genes. Participants were asked to make four predictions concerning the eye color and to provide a justification for each of their choices (see Appendix A). Responses were classified into five categories: (a) *mother bias*, predicting that the offspring would resemble the mother on three or four out of four instances, and providing justifications indicating that the mother influences eye color; (b) *father bias*, predicting that the offspring would resemble the father on three or four out of four instances and providing justifications indicating that the father influences eye color; (c) *both parents*, predicting that the offspring would resemble both parents on three or four of four instances and providing justifications indicating that both mother and father influences eye color; (d) *other trend*, predicting eye color based on some principle (e.g., the son is similar to one parent and the daughter is similar to the other, siblings have same or different eye color, trait is dominant or recessive) and providing justifications that are consistent with this trend; and (e) *random pattern*, choices and justifications do not seem to follow any particular principle.

Only eleven children in Grade 2 provided responses that followed a discernable principle. Seven of these children were classified into the mother-bias category and four were classified into the both-parents category. Most children in Grade 2 (65%) were classified into the random category because their predictions across the four instances did not appear to follow any principle, or because they were unable to provide a consistent explanation across the four instances. Generally, these children said that the offspring would resemble one or both parents, but which parent they chose across the four instances did not follow a clear pattern. Twenty-two children in Grade 2 provided responses that also included other ideas, such as, God, growth processes, the environment, species affiliation, personal observations (anecdotes), statistical variation, and feature correlation (e.g., blond children tend to have blue eyes).

Responses generated by children in Grade 4 were similar to the response patterns outlined above. Fifteen children in Grade 4 gave responses that appeared to follow some sort of principle; two children displayed a mother bias, one child thought eye color was sex-linked (boys resemble fathers, girls resemble mothers), and twelve children thought that both parents contribute to eye color. Fifty-three percent (seventeen children) in Grade 4 were classified into the random category. Most children referred to one or both parents in their explanations, but twenty children also referred to other ideas. Examples included God, growth processes, birth order, personal observations, statistical variation, and feature correlation.

Nineteen children in Grade 6 provided responses that appeared to follow some sort of principle. One child showed a father bias and eighteen children thought that both parents contribute to eye color. Thirty-four percent (11 children) gave random responses and two children said they were unsure of the reasons for eye color. Most explanations included references to one or both parents, but fifteen children also made references to other ideas, such as personal observations, statistical variation, and feature correlation.

Almost all adults (29 out of 32) provided a clear response pattern that was genetically based. Nineteen adults were classified into the both-parents category (e.g., get genes from both parents), one adult showed a father-bias, and nine adults used the genetic principle of dominance (regardless of the parent's sex, offspring will inherit brown eyes because the brown allele is dominant over blue). One adult made predictions that appeared random, but consistently used a genetic explanation to support his predictions. Two adults said they were unsure of the reasons underlying eye color. Seven adults generated explanations that included ideas other than genetic contribution from parents, including statistical variation and personal observations.

Figure C-1
Percentage of Participants Who Chose Each Option
Item 1a: Size of Ears - Unrelated Infant

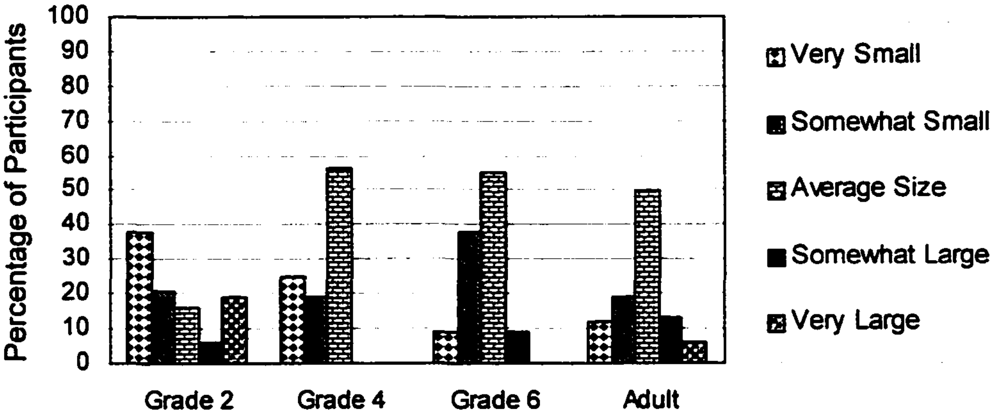


Figure C-2
Percentage of Participants Who Chose Each Option
Item 1b: Size of Ears - Related Infant

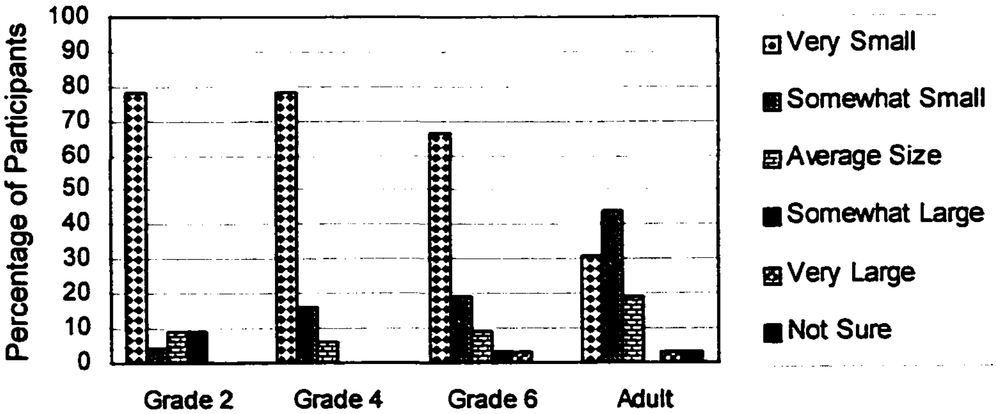


Figure C-3
Percentage of Participants Who Chose Each Option
Item 2a: Size of Heart - Unrelated Infant

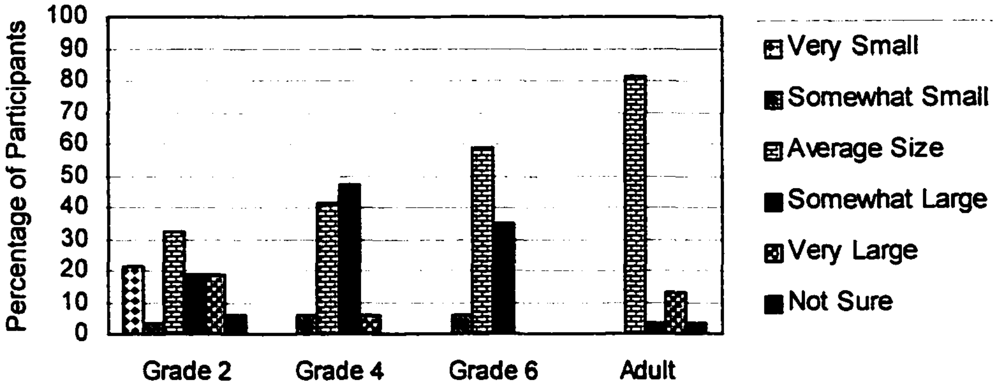


Figure C-4
Percentage of Participants Who Chose Each Option
Item 2c: Size of Heart - Related Infant

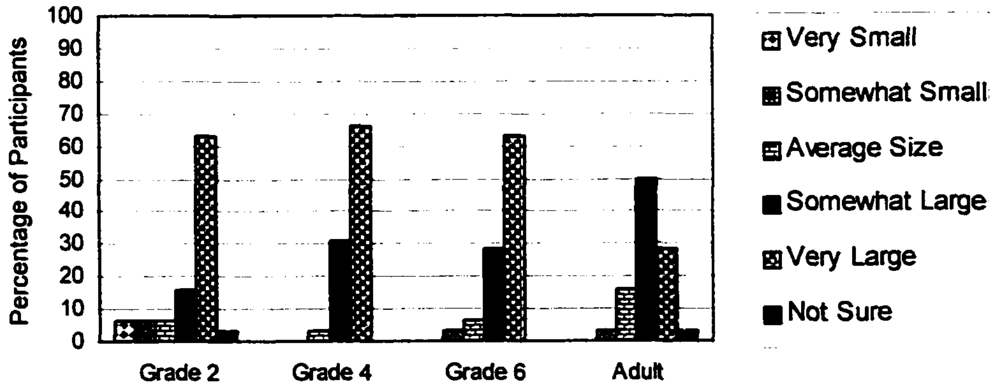


Figure C-5
Percentage of Participants Who Chose Each Option
Item 3a: Parents vs Friends

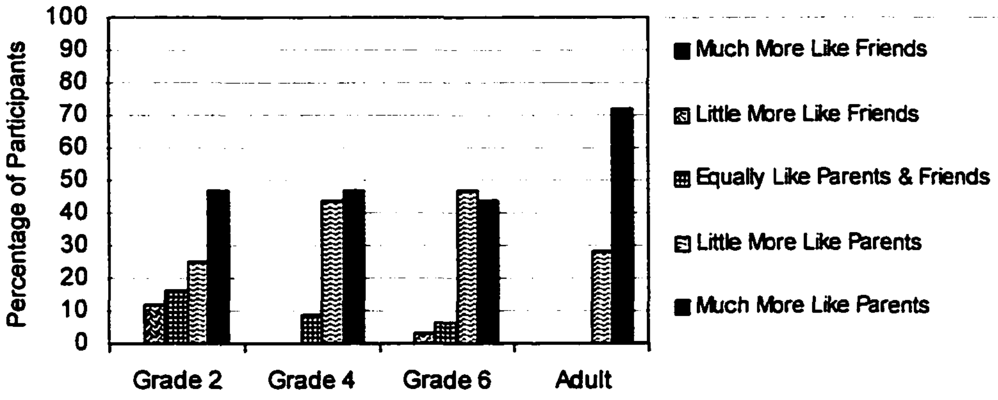


Figure C-6
Percentage of Participants Who Chose Each Option
Item 3b: Parents Vs Grandparents

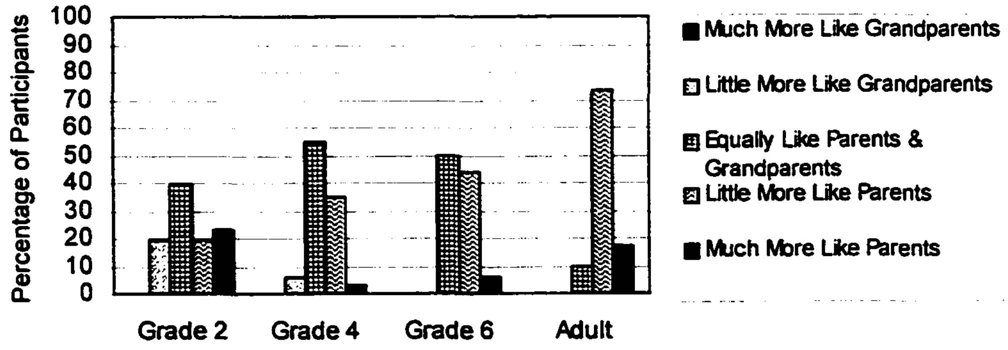


Figure C-7
Percentage Of Participants Who Chose Each Option
Item 4: Adoptive vs Biological Parents

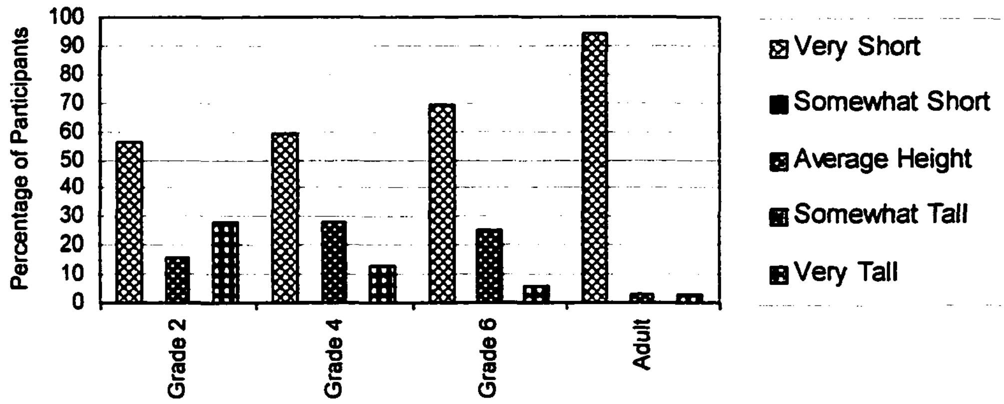


Figure C-8
Percentage of Participants Who Chose Each Option
Item 5: Transmission of Acquired Traits