The Development of Scientific Understanding: Children's Construction of Their First Biological Theory

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Abstract

This thesis addresses the debate in developmental cognitive science regarding the nature and development of children's first intuitive theory of biology. Chapter 1 consists of an extensive literature review of previous studies in the field of children's biological knowledge, with an emphasis on delineating what we mean by "theory" and evaluating previous claims in light of this analysis. Chapters 2 and 3 present experimental studies addressing children's early notion of bodily functioning, in particular with respect to two potential biological explanatory principles (teleology and vitalism). Chapter 4 presents another experimental study exploring the question of whether or not plants play any role in children's early biological theory. Finally, in Chapter 5, we synthesize the results of the studies presented in Chapters 2 - 4, and discuss them in terms of our general question: "When can children be said to have an autonomous biological theory, and how can we characterize that theory?" We argue that children's first biological theory emerges between the ages of 4 and 6, and that its ontology consists specifically of animals (with plants not being added until a later age). Finally, we discuss the relationship between vitalism and biological teleology as causal principles in this theory, and suggest a story for how this first theory might be constructed.

Thesis Supervisor: Susan Carey
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CHAPTER 1:

The Debate about Children's First Biological Theory: What Was the Question Again?

1.1. Introduction

In recent years, cognitive psychology has witnessed a monumental surge in the number of researchers pursuing the idea that cognition may differ markedly across various content areas or domains (e.g., Carey, 1985b, 1991; Carey & Spelke, 1994; Gopnik & Wellman, 1994; Inagaki & Hatano, 1993; Keil, 1992, 1994; Springer, 1992; Springer & Keil, 1989, 1991; Vosniadou & Brewer, 1992; Wellman & Gelman, 1992). The general claim is that an individual's knowledge of the world is divided into different cognitive domains, each of which is organized and structured according to a different intuitive theoretical framework. These intuitive theoretical frameworks can simply be thought of as people's everyday understandings of certain bodies of information such as intuitive mechanics and intuitive astronomy. Cognitive development, according to this view, is best characterized as a process of theory elaboration and theory change about different content-specific cognitive domains (e.g., Carey, 1985a; Carey & Spelke, 1994; Keil, 1994; Wellman & Gelman, 1992).

Of the several potential candidates for cognitive domains that have been proposed in the literature, there is virtually unanimous agreement that two of these domains, intuitive mechanics and intuitive psychology, are present in very young children and most likely have their basis in the innately specified architecture of the mind (e.g., Carey & Spelke, 1994; Gopnik & Wellman, 1994; Leslie, 1994; Spelke, 1991). The status of a third potential domain -- intuitive biology -- is much more controversial. There are both theoretical arguments and empirical studies purporting to show that: (a) before the age of 10, children don't have a cognitive domain of "biology" at all, and that any understanding they have of biological phenomena before this age is subsumed under their theory of psychology (Carey, 1985b); (b) by at least 6 years of age, children possess an autonomous cognitive domain of biology, but this domain is structured around different causal principles than those present in the intuitive theory of older children and adults (Hatano & Inagaki, 1994; Inagaki & Hatano, 1993); and (c) children as young as age 3 may have an autonomous cognitive domain of biology which is structured around a skeletal version of the causal principles present in the adult theory (Keil, 1992, 1994).

In order to address this issue of when and how an intuitive biology emerges, two things are necessary. First, we must characterize precisely what we mean by the words "domain" and "theory". Second, we must delineate exactly what type of evidence we would need to decide when a child has an autonomous cognitive domain, or theory, of biology.

1.2. Steps Toward Addressing the Biology Debate

To address the first question -- we define an intuitive theory as consisting of two basic components: the WHAT and the WHY (cf. Carey, 1995; Wellman & Gelman, 1992). The WHAT component simply tells us the types of things that are governed by the theory. This component can be further broken down into two more basic elements: the ontology and the phenomena. The ontology specifies the entities in the world that are covered by the theory, while the phenomena specify the types of processes or interactions of these entities which are to be explained. The WHY component consists of domain-specific causal explanatory principles that we use when we reason about the WHAT in the theory. For example, in the adult theory of intuitive mechanics, the ontology consists of physical objects, the phenomena to be explained are the mechanical interactions between those objects, and the explanatory principles are the laws of contact mechanics. Thus, we would explain that a bowling pin fell over because a bowling ball rolled into it. In the adult theory of intuitive psychology, the ontology consists of agentive beings, the phenomena to be explained are the purposive behaviors of those beings, and the explanatory principles are the laws of folk psychology (which explain behavior by appealing to mental states, specifically beliefs and desires). Thus, we would explain that John opened the freezer because he wanted ice cream and he believed that there was ice cream in the freezer.

The notion of "domain," in this view, is a domain of phenomena predicated over the entities in the theory. In other words, the domain can be said to equal the WHAT component of the theory. Crucially, however, it is important to note that the causal explanatory principles (i.e., the WHY) and the domain (i.e., the WHAT) are not separable entities. Specifically, the explanatory principles determine what we include in the domain (Carey & Spelke, 1994; Gopnik & Wellman, 1994). For example, consider the domain of intuitive psychology. In this domain, we reason about the actions of agentive beings in terms of their mental states, specifically their beliefs and desires. By and large, the entities included in this domain are also biological beings, specifically animals. Therefore, when we encounter an object which is not a biological being, it is a safe bet to immediately classify this as not belonging in our psychological domain. However, suppose that we receive evidence which shows that this object behaves exactly in accordance with our psychological explanatory principles. It seems clear that we would immediately re-assign the object's ontological status, such that it would now be included in our psychological domain.[1]

The second issue we must tackle before we can sensibly discuss how an intuitive biology emerges is that of delineating exactly what types of evidence we require to establish that a child in fact possesses a theory of biology. These criteria should follow directly from our definition of what constitutes an intuitive theory. First, we should require that the child be able to pick out a biological ontology -- that is, that she can differentiate biological from non-biological entities. Second, we should require that the child be able to pick out biological phenomena -- that is, that he can differentiate between biological and non-biological processes. Note, however, that given the importance of explanatory principles for determining the inclusion of the domain, these two criteria by themselves are not sufficient to establish that the child possesses a theory of biology. In other words, it is possible for the child to make distinctions in the world which are co-extensive with the distinctions we (as adults) would make on the basis of our biological theory (e.g., animal vs. inanimate object; mental processes vs. physiological processes) without any reference to biological criteria at all. In particular, we will argue that the distinctions that young children make which have been cited in the literature as being "biological" distinctions can instead be made on the basis of

[1] For those readers who are skeptical, we suggest that you watch Disney's movie *Aladdin* and monitor your own thinking about the magic carpet in this movie.

psychological or social criteria, or even on the basis of atheoretical factual knowledge, and thus do not necessarily entail specifically biological knowledge at all. In order to claim that the child is making these distinctions on biological grounds (i.e., that she has a biological theory), we must require that the child uses biologically-specific causal explanatory principles to reason about the phenomena in the domain. This requirement has two components: (1) The child must have some sort of causal principles with which to explain the phenomena; and (2) The child must use these principles to explain only biological phenomena.[2]

Using these criteria as a guide, we next examine exactly what evidence we have that young children possess an intuitive theory of biology.

1.3. Evidence for an Intuitive Biology in Children

1.3.1. Criterion 1: Distinguishes biological from non-biological entities

There are two types of evidence one might use to determine whether or not children distinguish biological from non-biological entities. The most intuitive way might simply be to ask them whether or not various objects are alive, and why. Exactly this experiment has been performed many times (e.g., Piaget, 1929; Klingensmith, 1953; Klingberg, 1957; Laurendeau & Pinard, 1962; Carey, 1985b; Stavy & Wax, 1989; Hatano et al., 1993; Sonntag & Behrend, 1993). Essentially, the results of these studies show that before approximately 10 years of age, children: (1) over-attribute "aliveness" to many inanimate objects, perhaps on the basis of motion, activity, usefulness, or anthropomorphic traits; and (2) fail to consistently attribute "aliveness" to plants.[3]

These results appear to argue against the idea that young children (before the age of 10) possess a biological ontology. However, this conclusion is unwarranted for two reasons. First,

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[2] There is a bit of a circularity problem here. On the one hand, we say that to count as domain-specific, a principle must explain only phenomena in the domain. On the other hand, we argue that explanatory principles determine what is included in the domain. The way out of this is as follows: For the purposes of determining what counts as a biological principle, what we mean by "domain-specific" is that it must explain only those phenomena that would be considered biological in the adult theory (or a subset of these).

[3] Children in Israel tend to deny "aliveness" to plants even through the age of 15, perhaps because the Hebrew language treats plants and animals very differently (Hatano et al., 1993; Stavy & Wax, 1989).

as Carey (1985b) pointed out, it is very possible that, for the child, the word "alive" doesn't map onto the *living thing/inanimate object* distinction that we are trying to probe. In her study, Carey provided evidence that many of the children tested were instead using the word "alive" to mark the distinction between *alive/dead* or *real/imaginary*. Obviously, if children are mapping "alive" onto the wrong conceptual distinction, then studies such as these can't tell us anything about the child's representation of a biological ontology. Second, even if children do not represent the adult's biological ontology of *living thing*, it is very possible that they do represent a biological ontology which is a subset of this -- namely, *animal*. Our criteria for crediting a child with an intuitive biology simply require that he represent a biological ontology. There is no reason to preclude a priori the possibility that the child could possess a full-blown biological theory which only encompasses the ontological kind *animal*, and which later comes to include plants.

A second way of determining whether children distinguish biological from non-biological entities is to see whether these entities pattern differently with regard to children's judgments of various phenomena. In other words, does the child expect certain phenomena to occur only in biological, but not in non-biological, entities? There is evidence that for a variety of phenomena, children do expect this at a very young age.

Gelman, Spelke, and Meck (1983), for example, asked preschool children simple yes/no questions about a number of potential actions, component parts, and mental/emotional states of people, animals, and inanimate objects. Their results showed that the children treated animals and people differently than inanimate objects, in the sense that both animals and people were judged able to have feelings and autonomous movement, and to reciprocate actions. However, although this clearly shows a differentiation between animals and inanimates in the children's minds, we must be cautious about attributing a biological ontology to the children based on these results. The attributes on which the children were making these distinctions are better characterized as falling under the rubric of a psychological, rather than a biological, domain. Therefore, this study may simply be confirming for us that young children have a psychological ontology.

Putatively stronger evidence for an ontological differentiation along biological lines comes from studies examining children's understanding of the processes of growth and healing. Rosengren, Gelman, Kalish, and McCormick (1991) showed children pictures of animals and artifacts and asked the children to pick a second picture depicting what the animal or artifact would look like after a long time. Children as young as age 3 appeared to understand that animals, but not artifacts, get larger with age. Inagaki and Hatano (in press) performed a similar study, but also asked about plants in addition to animals and artifacts. Children as young as age 4 thought that both plants and animals get bigger with time, but that artifacts tend not to. In a related study, Backscheider, Shatz, and Gelman (1993) told children that some animals, plants, and inanimates had been damaged, and then asked the children: (a) whether these objects could heal through re-growth; and (b) whether a person could fix them. Three- and four-year-old children realized that both animals and plants could regrow while inanimates couldn't. In each of these studies, then, young children differentiated between animals and (sometimes) plants, on the one hand, and inanimates, on the other, with respect to growth or regrowth.

Further evidence for children's biological ontological differentiation comes from Springer and Keil's (1991) study of children's beliefs about possible mechanisms of color inheritance in different ontological kinds. In this study, they told children about an animal, a plant, and an inanimate object which had a certain color, and then asked the children to choose from a set of possible explanations for how the object had gotten that color. Their results showed that 4- and 5-year-old children expected the inanimate object to have gotten its color due to human intervention, while they expected the plant and animal to have gotten their colors from natural causes. The children also appeared to differentiate mechanisms for the plant and the animal, preferring only internal causes for the animal, but preferring both internal and external causes for the plant. Thus, young children differentiated between animals, plants, and inanimates with respect to the process of color inheritance.

Attribution tasks have provided additional evidence for children's biological ontological differentiation. Carey (1985b) asked children and adults whether various animals, plants, and inanimate objects possessed certain "animal properties" (e.g., having bones). The main result was that the youngest children (ages 4 and 5) tended to underattribute these characteristics to animals other than people, with less attributions occurring the less similar the animal is to people. For example, more children judged that mammals have hearts than that birds do, and more judged that birds have hearts than that bugs do. In addition, however, there was a sharp break in attributions to animals versus plants or inanimate objects. In other words, children tended not to attribute animal properties to non-animals. Similarly, Simons and Keil (1995) asked children to pick the appropriate insides (e.g., guts, gears, or rocks) for various animals and machines. Even at ages 3 and 4, children picked different insides for animals and machines (although they didn't necessarily choose the correct insides until about age 8). Thus, children distinguished between animals and non-animals on the basis of what properties they believe animals and non-animals to possess.

Finally, Keil (1989) performed a series of studies in which he told children stories about a scientist changing one thing into another by a series of transformations. For example, in one story the scientist took a raccoon, dyed it black and white like a skunk, surgically inserted a sac of smelly stuff into it, and taught it to act like a skunk. The children's task was simply to decide whether in the end it was "really" still the first thing (e.g., a raccoon) or was "really" the second thing (e.g., a skunk). Keil found that the youngest children (age 5): (1) virtually always accepted the transformation if it took place within the category of inanimate objects or of plants; (2) sometimes accepted the transformation if it took place within the category of animal; and (3) virtually never accepted the transformation if it crossed these ontological boundaries (i.e., machine --> animal; animal --> plant; animal --> inanimate). This result strongly suggests that the children were making some ontological distinction between animals versus other kinds of things.

In sum, previous studies which intended to show that children do not differentiate between biological and non-biological entities on the basis of their judgments of which things are "alive" are misguided for two reasons. First, the word "alive" simply may not map onto the *living-thing/inanimate object* distinction we are trying to probe. Second, even if children do not represent the adult's biological ontology of *living thing*, they still might represent a biological ontology which consists of only *animal*. When we look at more subtle evidence, we see that on a variety of tasks, children apparently do differentiate between animals and inanimate objects[4] with respect to the type of phenomena which the children believe apply to them (specifically, mental states, growth, possession and transmission of properties, and kind transformation). We thus conclude that preschool children represent something which is a candidate for a biological ontology.

It is important to realize, however, that these studies have as yet told us nothing about the basis on which the children are making these distinctions. In other words, we don't know what this ontology is an ontology of. While it may be tempting to call this a biological ontology, this is perhaps only because it is a biological ontology for us (see Carey's [1995] discussion of theory-laden attribution). Notice, however, that this same ontology could be picked out on the basis of purely psychological criteria. That is, the classes of entities arising from the distinctions the children make could be described as either: (1) organisms in a psychological ontology, or (2) organisms in a restricted biological ontology (i.e., one not including plants). Thus, whether we're justified in calling these distinctions a biological ontology for the children will hinge on whether or not they have something we might call biological causal-explanatory principles which are specific to this ontology.

1.3.2. Criterion 2: Distinguishes biological from non-biological phenomena

Our second criterion for attributing an intuitive biology to young children is that they be able to pick out biological phenomena. In a sense, the evidence presented in the previous section could be relevant here as well. That is, the fact that children know, for example, that animals grow while inanimate objects do not could be taken as evidence either for a potential biological ontology (i.e., animals) or for a potential biological phenomenon (i.e., growth). However, this is rather indirect evidence, in that it doesn't require children to explicitly distinguish biological phenomena from non-biological phenomena. A more direct way of asking the question is whether, within their potentially biological ontology (i.e., animals), children are able to differentiate between biological and non-biological phenomena. The evidence which has been put forth concerning this issue

[4] The status of plants is less clear. We will temporarily table our discussion of where plants fit into this conceptual landscape, and will address this issue explicitly in Chapter 4.

comes from studies of children's beliefs regarding inheritance and disease.

In a study of children's beliefs about inheritance, Springer (1992) told children that a pictured animal had a particular property (e.g., "This duck can see in the dark."). He then asked them whether each of two other animals, described as the first animal's "baby" and "friend", shared this same property. Children as young as age 4 expected the baby to share more stable physical characteristics, but not more social or behavioral characteristics, than the friend. In a similar study, Springer and Keil (1989) told children that both parents of an animal had an unusual property (e.g., pink hearts), and asked them whether the baby would share that same property. Among the preschoolers (ages 4 and 5), properties with physiological functional consequences were judged to be inherited more often than chance, while properties with social or psychological functional consequences were not. These studies thus provide evidence that, with respect to heritability, preschool children make some differentiations between physical/physiological and social/psychological properties.

In studies of disease, two issues are relevant. The first deals with children's knowledge of disease causation. Siegal (1988) showed children videotapes of a puppet with a cold that the puppet explained came from either: (a) playing with a sick friend, or (b) doing something naughty. The children were then asked whether or not the puppet's explanation was correct. Four- and five-year-old children judged the puppet's explanation to be correct in the former case, but wrong in the latter. In another study (Springer & Ruckel, 1992), preschool children were told something bad about a food, and were then asked if a boy would get sick if he ate that food. When the information they had been given was physiologically relevant (e.g., "he waited until it got very old before eating it"), but not when the information was socially relevant (e.g., "he had stolen it"), the 4- and 5-year-old children judged that the boy would get sick. These studies thus suggest that, with respect to disease causation, preschool children make some differentiations between physical and social factors.

A second disease issue deals with the types of symptoms children believe are contagious. Keil (1992, 1994) told preschoolers stories about two children who were visiting with each other for the weekend. One of these children was always described as having some set of symptoms. After hearing each story, the children were asked whether the second child was likely to catch those symptoms. The results showed that 4-year-olds expected physiological symptoms (e.g., can't digest vegetables) to be potentially contagious, but not behavioral symptoms (e.g., obsessive hand-washing). Thus, with respect to disease contagion, preschool children differentiate between physiological and psychological factors.

In sum, the above studies show that, by 4 or 5 years of age, children differentiate between physical or physiological properties versus social or psychological properties, at least so far as their relevance for inheritance, disease causation, and disease contagion. We thus conclude that preschool children represent something which is a candidate for a class of biological phenomena. As with the ontology, however, we must be very cautious about attaching the "biological" label to these phenomena prematurely. Given that we know that by age 4, children know a lot about both the psychological and social worlds (Wellman, 1990; Wellman & Gelman, 1992), it is possible that they could be making these distinctions on the basis of socially or psychologically relevant versus not socially or psychologically relevant, rather than on the basis of biological versus social/psychological, per se. For example, in Keil's (1992, 1994) contagion study, children could have judged that behaviors are not contagious because they already have explanations for behaviors which are in terms of wants, beliefs, etc. Alternatively, children might be making some of these distinctions on the basis of unexplained facts that they have learned about the world -- for example, that you can catch a cold from being around sick friends (cf. Siegal, 1988). In neither of these cases would we want to call these distinctions "biological". So again, whether we're justified in calling this a class of biological phenomena for the children will hinge on whether or not they have something we might call biological causal explanatory principles which they use to explain and reason about these phenomena.

1.3.3. Criterion 3: Domain-specific causal explanatory principles

Based on the evidence reviewed in the previous sections, we concluded that preschool children represent classes of things which are potential candidates for a biological ontology and biological phenomena. But this isn't enough to allow us to attribute a cognitive domain of biology to them. We also pointed out that these exact distinctions could in principle be made on the basis of either: (a) the children's knowledge in the psychological and social domains; or (b) atheoretical facts that the children have learned. Without any evidence as to how the child is in fact making these distinctions, we have no way of knowing whether to classify the child's knowledge as psychological, biological, or atheoretical in nature. Let us be very clear about this point. The form of our argument is not of the following type: "Children need three things for us to attribute a domain of biology to them: a biological ontology, biological phenomena, and biologically-specific causal principles. They've got at least the first two, so they've almost got it, but we just don't know about the third." Rather, the argument we are making is that in the absence of evidence about their causal principles, we have no basis for attributing knowledge of either a biological ontology or biological phenomena to the child. That is, without the third, they have neither the first nor the second.

Given the above argument, the question of whether we can attribute an intuitive biology to young children comes down to simply this: "Do preschool children have any domain-specific causal explanatory principles that they use to reason about biological entities and phenomena?" If so, then we will conclude that, contrary to Carey's (1985b) claims, children as young as age 4 or 5 possess an autonomous intuitive theory of biology. Exactly how we would then characterize this theory would depend on what specific principles we find guiding the children's reasoning in this domain. If not, then we would conclude that, contrary to Keil's (1992, 1994) and Inagaki and Hatano's (1993) claims, young children do not possess an autonomous cognitive domain of biology, and their reputed classes of a biological ontology and phenomena can rather be explained by appealing to something like their knowledge in the psychological or social domains (i.e., they know what applies to their psychological/social domains and what doesn't), or to their atheoretical, factual knowledge about the world (e.g., animals grow). Our question is two-fold. First, do they have any causal principles? Second, are these principles specifically biological?

In the quest for a biological explanatory principle in children's reasoning, three potential candidates have been proposed: (1) Essentialism (Atran, 1990); (2) Teleology (Keil, 1992, 1994); and (3) Vitalism (Inagaki & Hatano, 1993). Briefly, essentialism is the idea that biological kinds possess an inherent, underlying "essence" which is responsible for its characteristic properties; teleology is the idea that properties of biological kinds are explained in terms of what they are <u>for</u>; and vitalism is the idea that body functioning is mediated by a "vital force", which is something that is undifferentiated between substance, energy, and information.

In the following section, we discuss the first of these candidates -- essentialism -- and present evidence suggesting that it is not domain-specific, and therefore does not fulfill our criteria for a biological causal principle. The remaining potential biological principles -- teleology and vitalism -- will be taken up in Chapters 2 and 3 respectively.

1.4. Is Essentialism a Biological Principle?

Atran (1990, 1994) suggests that, universally, people presume that biological kinds possess an inherent underlying "essence" which is responsible for its teleological growth, characteristic behavior, and morphology. It is due to this essentialist belief that we would say, for example, that a dog born legless was missing "its" legs, but would not analogously say that a legless beanbag chair was missing "its" legs. This proposed essentialism appears to function strongly in adults' and older children's reasoning about biological kinds, and has thus been proposed as a potential causal explanatory principle around which children's theory of biology may be organized (Gelman, Coley, & Gottfried, 1994; Keil, 1992, 1994)

Experimental evidence for essentialist reasoning in children's biological thought is provided by Keil's (1989) transformation studies described earlier. In these tasks, 9-year-old children generally accepted the transformations in the case of artifacts (e.g., if you change a coffeepot into a birdfeeder, then it's a birdfeeder), but categorically rejected the transformations in the case of animals (e.g., if you change a skunk into a raccoon, it's <u>still</u> a skunk). This result can be explained by positing that the children believe that animals, but not artifacts, have an underlying essence that can't be altered, and that makes the animal what it "really" is. But what of younger children? When 5-year-olds were tested on this task, they generally accepted the transformations for <u>both</u> artifacts and animals. This suggests that these younger children do not yet have this essentialist belief which appears to be guiding the responses of the older children.[5]

In a converse type of study, Keil (1989) told children and adults stories about natural kinds and artifacts which had the characteristic features and behaviors of one particular kind (e.g., looked and acted like horses), but then scientists discovered that they really had the deeper features of a different kind (e.g., internal parts of a cow, cow parents, and cow babies). The subjects were asked whether this discovery made a difference in the classification of the items (e.g., "Are they really horses or cows?"). As in the transformation study, older children (age 9) and adults said that natural kind, but not artifact kind, was determined by the deeper features. In contrast to the older children, younger children (ages 5 and 7) tended to reject the idea that deeper features were diagnostic of kind for both artifacts and natural kinds. Like the transformation study, the results of this study can be explained by positing that older children and adults believe that animals (or perhaps natural kinds) have essences which are reflected in their deeper features, and which determine kind membership. However, evidence of this belief is absent in young children, and seems to develop with age.

There is a problem, however, with accepting Keil's (1989) tasks as evidence of essentialism as a biological causal principle. According to Gelman (1989), there are three similar distinctions which one must consider: (1) animate versus inanimate (i.e., animal vs. non-animal); (2) biological versus non-biological (i.e., plants and animals vs. everything else); and (3) natural kind versus artifact kind (i.e., natural vs. man-made). To count as a biological principle, we would argue, essentialism must adhere to either the distinction between biological and non-biological, or potentially between animate and inanimate (i.e., if the child's biological theory

[5] A second interpretation is suggested by another Keil (1989) task, in which he varied the type of transformation that took place. In this study, he found that even the 5-year-olds wouldn't accept the transformations if they were simply due to a costume, while older children would accept the transformations if they were caused by an injection given shortly after birth. Thus, it may be that younger children do believe that animals have essences, but simply have different criteria for the types of things which can affect that essence.

includes only animals). Unfortunately, in both of Keil's tasks, there seems to be no difference in children's performance with respect to biological natural kinds (e.g., horse - zebra; maple tree - pine tree) versus non-biological natural kinds (e.g., diamond - pearl). It thus appears that the distinction children are making in these tasks is natural kind versus artifact kind -- and is therefore not indicative of a biological causal principle.

Other potential evidence for children's essentialistic reasoning comes from Gelman and Wellman (1991), who performed a study very similar to Keil's (1989) transformation study, but using simpler transformations. Specifically, for each item, 4- and 5-year-old children were asked to consider three transformations: (1) having its "insides" removed; (2) having its "outsides" removed; and (3) movement. Items fell into two categories: (a) insides-relevant items, in which the insides were critical to the identity and functioning of the object (e.g., dog); and (b) insides-irrelevant items, in which this was not the case (e.g., refrigerator). For each transformation, children were asked about the object's identity (e.g., "Is it still a dog?") and its function (e.g., "Can it still bark and eat dog food?"). For the insides-relevant items, children said that if the insides, but not the outsides, were removed, then the identity and function of the object would change. Notice, however, that although this may be a demonstration of essentialistic reasoning in very young children, the distinction between insides-relevant versus insides-irrelevant items did not map onto any biological domain. That is, the insides-relevant category included not only biological kinds like *dog* and *turtle*, but also non-biological kinds such as *car*, *book*, and *pencil*. Thus, essentialistic reasoning as demonstrated in this study was again not biology-specific, and therefore does not fulfill our criteria for a biological causal principle.

Finally, further potential evidence for essentialistic reasoning has come from several studies dealing with inductive inference within categories. The idea behind this argument is that if we assume that category members share an essence, then we should also assume that because of this shared essence, category members will share deep commonalities in both observable and unobservable features (Gelman et al., 1994). Thus, categories which share an essence should support inductive reasoning. To test this, Susan Gelman and her colleagues have performed several induction experiments in which category membership was pitted against perceptual similarity as potential bases for inductive inference. In these studies, children as young as age 3 and 4 used category membership preferentially over perceptual similarity as a basis for drawing inferences about novel properties (Gelman & Markman, 1986, 1987), and children even as young as 2-1/2 used category membership to make inductive inferences about familiar properties (Gelman & Coley, 1990). These results, they argue, are at least consistent with the idea that very young children have an essentialist bias which allows them to use category membership as a basis for inference (Gelman et al., 1994).

The problem we run into again, however, is that of domain specificity. That is, if biological kinds, but not artifact kinds, are subject to essentialistic reasoning, then we would expect that biological categories support inductive inferences at least to a greater degree than artifact categories do. However, the induction studies instead show that preschool-aged children make no such distinction. In other words, although young children may think that biological categories are a good basis for induction, this belief is not specific to biological kinds -- they seem to believe that other natural kinds and even artifact categories support inductions to the same degree (Gelman, 1988, 1989; Gelman & Coley, 1990; Gelman & Markman, 1986, 1987).

In sum, we know that essentialism is a principle which guides adults' and older children's reasoning about biological kinds. However, in our review of several different kinds of evidence for essentialistic reasoning in children, we found each case to be deficient as evidence for biologically-specific essentialistic reasoning. Depending on the task, the youngest children (ages 2-1/2 to 5) seemed to: (a) treat all categories essentialistically (Gelman & Coley, 1990; Gelman & Markman, 1986, 1987); (b) treat all categories non-essentialistically (Keil, 1989); or treat some essentialistically and some non-essentialistically, but not according to any potentially biological distinction (Gelman & Wellman, 1991). Older children (age 9) seemed to possess a type of principled essentialistic distinction between different categories, but this distinction seemed to map onto the division between natural kind versus artifact kind, and was thus also not biology-specific. Therefore, we must conclude that essentialism is not a plausible candidate for a biological causal principle in children's theory of biology, and indeed is probably not a biologically-specific principle in adults' conceptual system either.

1.5. Plan for the Thesis

In this chapter, we have attempted to answer the following two-part question: "What does it mean to say that a child has an autonomous biological theory, and when can we conclude that a child possesses one?" We defined a biological theory (or any intuitive theory) as consisting of three requisite components: an ontology, phenomena, and domain-specific causal explanatory principles. Any debate about children's possession of a biological theory, we argued, must be answered in terms of these components.

Based on children's judgments regarding to which entities certain phenomena (e.g., growth, autonomous movement, kind transformations, particular types of inheritance) can apply, we concluded that children as young as age 4 or 5 represent a class of entities (approximately co-extensive with our adult notion of *animal*) which is potentially a biological ontology. Similarly, on the basis of their judgments regarding the type of properties (physical/physiological vs. social/psychological) which are relevant for certain processes (e.g., inheritance, disease causation, disease contagion), we concluded that children as young as age 4 or 5 also represent a class of potentially biological phenomena. In both cases, however, we cautioned that we did not know the basis on which the children were making these distinctions. While one possibility is that these distinctions fall out of the child's knowledge in a truly biological domain, two other equally valid possibilities are that these distinctions are the result of: (a) the child's knowledge about the psychological and social domains; and/or (b) atheoretical facts that the child has learned about the world. Whether we would be justified in crediting 4-year-old children with an autonomous cognitive domain of biology thus rested specifically on the question of whether we could find any causal explanatory principles by which they reason about these classes of a potentially biological ontology and phenomena.

In our search for a biological explanatory principle, we introduced three potential candidates: (1) Essentialism (Atran, 1990), (2) Teleology (Keil, 1992, 1994), and (3) Vitalism (Inagaki & Hatano, 1993). However, we concluded that essentialism does not satisfy our criterion of being specific to reasoning about a biological domain, and therefore cannot function as an explanatory principle around which young children's theory of biology might be built. This leaves teleology and vitalism as the remaining viable candidates around which a preschool child's biological theory might be constructed. In the remaining part of this thesis, we continue to explore this debate about the nature and development of children's intuitive theory of biology, with an explicit focus on potential causal explanatory principles.

Chapter 2 describes an empirical study addressing the possibility of teleology as a potential biological principle in children's reasoning. In this study, 4- to 10-year-old children were interviewed about their beliefs and knowledge of bodily organs and processes. We find a dramatic shift in children's functional explanations between the ages of 4 and 6, and suggest that this shift is precipitated by their discovery of "Life" as a biological goal for bodily function (i.e., the beginning of biological teleology).

Chapter 3 describes an experimental study which addresses the possibility of vitalism as a potential biological principle in children's reasoning. In this study, 4- to 8-year-old children were asked to judge different types of potential explanations for various bodily processes. We again find a dramatic shift between the ages of 4 and 6, which we suggest marks the emergence of vitalism as a causal principle in young children's reasoning.

Chapter 4 describes an experimental study addressing the claim in the literature that young children must have an autonomous theory of biology because they know that plants and animals share certain biological properties (e.g., growth). In this study, 6- to 10-year-old children were taught a novel mechanism for a "biological" property (e.g., growth) for either a plant, an animal, or a non-living thing (e.g., *zarches* make flowers get bigger). Based on children's patterns of projections of the mechanism to other entities, we find very little evidence of a unified living thing category (i.e., one that includes both plants and animals) before age 10, suggesting that plants are not a part of children's original biological theory.

Finally, in Chapter 5, we synthesize the results of the studies presented in Chapters 2 - 4, and discuss them in terms of our general question: "When can children be said to have an autonomous biological theory, and how can we characterize that theory?" We argue that children's first biological theory emerges between the ages of 4 and 6, and that its ontology consists specifically of animals (with plants not being added until a later age). Finally, we discuss the relationship between vitalism and biological teleology as causal principles in this theory, and suggest a story for how this first theory might be constructed.

CHAPTER 2:

Children's Knowledge of Bodily Organs and Substances: Evidence for Biological Teleology?

2.1. Introduction

In Chapter 1, we introduced the debate in developmental cognitive science regarding the nature and establishment of children's first intuitive biological theory. One of the major points of contention in this debate has been the presence or absence of causal explanatory principles in the child's reasoning about the entities in the theory. In other words, does the child use biologically-specific causal explanatory principles to reason about purportedly "biological" entities and processes? This requirement has two components: (1) The child must <u>have</u> some sort of causal principles with which to explain the phenomena; and (2) The child must use these principles to explain <u>only</u> biological phenomena.

Currently in the literature, there are three potential candidates which have been proposed as potential biological explanatory principles in children's reasoning: (1) Essentialism; (2) Teleology; and (3) Vitalism. Of these, however, essentialism is not domain-specific (see Chapter 1). The studies which have shown that young children reason essentialistically about animals have also demonstrated that young children reason essentialistically with respect to other natural kinds and complex artifacts (e.g., Gelman & Wellman, 1991). Thus, essentialism does not fulfill our criteria for a biological causal principle. This leaves teleology and vitalism as the remaining candidates around which a preschool child's biological theory <u>might</u> be constructed. The current study addresses one of these possibilities -- teleology as a potential biological principle.

<u>2.1.1 Teleology -- A Potential Biological Principle</u>

According to Keil's (1992, 1994) formulation of a functional/teleological explanatory principle, the properties of biological kinds are explained at least partly in terms of what they are <u>for</u>. For example, the types of answers to the question of why something has particular color patterns will be different for entities which are biological (e.g., chameleon -- because the colors camouflage the chameleon, making it harder for predators to find it) and non-biological (e.g., rainbow -- because of the refraction and reflection of the sun's rays by the water molecules in the air). Keil argues that this teleological principle is present universally in adults' reasoning, as suggested by the fact that arguments from this teleological stance occur repeatedly throughout history and across cultures as motivation for the existence of a god or gods (Dawkins, 1986). And in modern biology, it has been argued that this teleological reasoning leads to large-scale misconceptions in people's understandings of the processes of evolutionary biology (Gould & Lewontin, 1979).

Keil also claims that this teleological principle may be the first specifically biological explanatory schema in children's biology. To test this, he presented 5- and 7-year-old children with two explanations -- one teleological and one reductionist -- for why something had a particular property. For example, for the question, "Why are plants/emeralds green?", he offered the explanations: (a) "because it is better for the plants/emeralds to be green, and it helps there to be more plants/emeralds" [teleological]; and (b) "because there are little tiny parts in plants/emeralds that when mixed together give them a green color" [reductionist]. Overall, the children strongly preferred the teleological explanations for the "biological"[6] entities and the reductionist explanations for the "non-biological" entities (see Keil, 1992, 1994 for summary).

It appears, then, that by at least the early elementary school years, children demonstrate evidence of this teleological principle which characterizes adults' biological reasoning. Two caveats are in order here. First, we would like to see stronger demonstrations of this type of reasoning in younger children. In Keil's study described above, the result was largely due to the 7-year-olds; the 5-year-olds only "showed appropriate tendencies" (Keil, 1992). Second, even if these results hold true for the younger children, we still must be cautious about attributing a biological causal explanatory principle to them. As Carey (1995) argues, teleological/functional

[6] The use of the terms "biological" and "non-biological" of course constitutes a theory-laden attribution (cf. Carey, 1995). However, this is Keil's terminology, and since he does not describe his stimulus list further, we are unable to provide alternate labels for these categories.

reasoning is not specific to biology -- at the very least it is present in intuitive psychology, where we explain a person's behavior in terms of his or her goals (usually expressed as "wants" or "desires"). In order for us to attribute this type of reasoning as a biological principle for young children, it is not enough that they explain properties in terms of goals and functions -- we must also require that these goals and functions be specifically biological (e.g., to sustain life or health). Currently, it is still an open question when children start attributing biological goals to biological properties and processes.

2.1.2 Studies of Children's Knowledge of Bodily Function

In the current study, we explore children's explanations for the functions of bodily organs. The procedure was designed to elicit specifically functional explanations from the children (e.g., by asking directly, "What is X for?"). We hoped to accomplish two main goals. Our first goal was to provide a comprehensive description of the development of children's body knowledge across a range of ages. To do this, we introduce a coding hierarchy which deals with both the specificity and the correctness of children's functional explanations. Our second goal was to look for explicit evidence of biological teleology as an explanatory principle in young children's reasoning about the body.

To date, there have been very few comprehensive studies of children's bodily knowledge. Moreover, those studies that have been performed often provide very little quantitative information, but instead tend to report "the kinds of things" children say (e.g., Quiggin, 1977; Smith, 1977). Our main points of comparison will thus be targeted at the two most extensive studies that have been conducted so far.

In the first of these studies, Nagy (1953) gave written tests about the body to 220 children between the ages of 5 and 11. She asked them to draw various body organs, and asked extensive questions about the processes of digestion and respiration. Because Nagy did not analyze her data on the basis of the children's ages, however, we will only be able to discuss her results in terms of the global patterns she found.

In the other extensive study which addressed children's knowledge of bodily function, Gellert (1962) interviewed 96 children between the ages of 4 and 16. She first asked them to list the organs that are inside the body. Then she had them draw specific major organs (e.g., heart, stomach, liver), and asked about their functions. Unlike Nagy (1953), Gellert did analyze her data with respect to the children's ages, and her data will thus provide an invaluable basis of comparison with the results of the current study. Unfortunately, her youngest age grouping encompasses 4- through 6-year-olds into a single group. This is problematic for our purposes because, as we shall see, many interesting differences arise between the ages of 4 and 6 in the current study. Because of Gellert's grouping, we have no way of knowing whether these same differences were represented in her data as well.

In addition to these two comprehensive studies, other more specific studies of particular body organs will be discussed when relevant.

2.1.3 Some Predictions

In Chapter 1, we discussed the three positions in the literature regarding the status of intuitive biology in children's reasoning. These were as follows: (1) Before the age of about 10, children don't have a cognitive domain of "biology" at all, and any understanding they have of biological phenomena before this age is subsumed under their theory of psychology (Carey, 1985b). (2) By at least 6 years of age, children possess an autonomous cognitive domain of biology, but this domain is structured around different causal principles than those present in the intuitive theory of older children and adults (Inagaki & Hatano, 1993; Hatano & Inagaki, 1994). (3) Children as young as age 3 may have an autonomous cognitive domain of biology which is structured around a skeletal version of the causal principles present in the adult theory (Keil, 1992, 1994).

If we extend these positions to the area of bodily reasoning, we arrive at the following three predictions for the current study.

(1) Carey: We should expect a shift in reasoning between the ages of 7 and 10. This

marks the transition from psychological to biological principles in children's bodily reasoning.

(2) Inagaki and Hatano: We should also expect a shift in reasoning among older children (between ages 6 and 8-10). However, this will be indicative of children's shift from one biological causal principle to another.

(3) Keil: We shouldn't expect any changes in the type of reasoning children use at different ages. Rather, any developmental changes should be attributable to the gradual accumulation of factual knowledge, which is overlaid on the skeletal biological principles children purportedly have from a very young age.

2.2. Method & Plan of Analyses

2.2.1. Subjects

Forty-nine children served as subjects, twelve 4-year-olds (range 4;1 - 4;11; mean = 4;5), twelve 6-year-olds (range 6;2 - 6;11; mean = 6;7), twelve 8-year-olds (range 8;1 - 8;11; mean = 8;4), and thirteen 10-year-olds (range 10:1 - 10;11; mean = 10;7). Children were recruited from local day care centers and elementary schools. The data from two additional children (one 4-year-old and one 8-year-old) were excluded from the study due to their failure to complete both testing sessions.

2.2.2. Design

Children were tested individually in an unoccupied room at their school or day care center. The data for this study were collected as part of a larger study about children's understanding of body parts and processes (See Chapter 3). Each child participated in two testing sessions, each of which lasted approximately 10 to 20 minutes[7]. The current study concerns only the data collected in the first session.

[7] The data from the 10-year-olds were collected for the purpose of the current study only. They therefore participated in just one testing session.

2.2.3. Materials

Children were asked questions about 13 body parts: 8 internal (heart, brain, muscles, lungs, bones, blood, stomach, and nerves) and 5 external (eyes, teeth, hands, skin, and tongue). In order to keep the children from becoming frustrated, we attempted to ask the questions in such a way that "easy", or more familiar, body parts were interspersed among the "harder", or less familiar, body parts. All children were questioned about the body parts in the same invariant order. The children were also presented with an outline drawing of a body, on an 8-1/2" x 11" piece of paper, on which they were instructed to draw the body parts as they were mentioned. In addition, children were asked about two bodily processes (eating food and breathing air).

2.2.4. Procedure

After establishing rapport, the experimenter told the children that she was interested in discovering what children knew and thought about the body. She then told the children that she was going to ask them "all kinds of questions" about the body. As a warm-up task, the children were asked to "name as many parts of the body" as they could think of. As they named the parts, they were always given positive encouragement, and told that they were doing well. If they named only external body parts, they were asked, "How about inside the body? What kind of things are in the body?" This task continued until the children indicated that they couldn't think of any more body parts.

Next, the children were presented with an outline drawing of a body. The experimenter told them that she was now going to ask them questions about specific parts of the body. For each body part, the children were asked three questions: (1) "Where is X?" [They were asked to draw it on the picture]; (2) "What is X for?"; and (3) "What would happen if somebody didn't have X?" Children were given as much time as they needed to answer each question, and if they were silent or said they didn't know, they were asked to guess. Regardless of their answers, children were always provided with positive encouragement, and told they were doing well.

As the children were answering the questions, a student colleague drew a copy of their body drawing on a separate body outline, along with labels for the various body parts. She also made notes about the children's responses to the various questions. In addition, the entire session was audio-taped. The experimenter later went back through the audiotape of the testing session, and transcribed the children's answers to the questions from the tape.

As a final task, children were asked about two bodily processes: eating food and breathing air. Specifically, they were asked: (1a) "Why do we eat food?"; (1b) "What happens to the food that we eat?"; and (2a) "Why do we breathe air?"; (2b) "What happens to the air that we breathe?"

2.2.5. Coding for Body Part Functions

Children's responses to "What is X for?" and "What would happen if someone didn't have [a(n)] X?" were coded with respect to each of the ideas the child expressed. Children's answers to both questions were combined for each body part. For example, if for the heart, the child had answered: (A) "It beats, so that you can live", and without it (B) "it wouldn't clean your blood; you'd die", she would be credited with three ideas: (1) it beats [expressed once in A]; (2) you need it to live [expressed in both A and B]; and (3) it cleans your blood [expressed once in B].

For each individual body part, a hierarchy of responses was created, ranging from the lowest score for "don't know" to the highest score for the body part's canonical biological function (e.g., "pumps blood" for heart). For 12 of the 13 body parts (all except hands), what constituted the "canonical function" was chosen by consulting an illustrated reference book about the human body written for children (Bruun & Bruun, 1982). The coding hierarchies conformed to the following general scheme[8]:

Level 0: don't know; tautology (e.g., blood is for bleeding)

Level 1: general body function (e.g., for Life, health; for body or specific body part [without further specification])

Level 2: "incorrect" specific body function

Level 3 and above: canonical function (sometimes divided into more specific levels).

[8] See results for each body part for specific coding hierarchies.

A child was credited with an explanation level corresponding to the highest score among all the ideas she expressed for that body part. For example, if a child said that blood is "for bleeding" [score = 0] and that without it "you would die" [score = 1], he would be credited with a Level 1 explanation.

To assess reliability, a research assistant independently coded a random 50% of children's responses. Reliability between the two coders was 94%.

<u>2.2.6. Plan for Analyses</u>

Results will be presented in the following order. First, we will examine the internal body parts in terms of the following body "systems": circulatory, respiratory, digestive, nervous, and musculo-skeletal. We do not mean to imply that these systems function as such in the children's bodily knowledge -- in fact we would argue that, at least for the younger children, they definitely do not. This grouping simply allows us a way of organizing and discussing children's bodily knowledge. Note that children were not questioned about the body parts in this order. For each system, we will examine first the location and then the functions of the body organs involved. In addition, the respiratory and digestive systems include children's answers to the questions of why we eat food and breathe air, and what happens to that food and air. After this examination of internal body parts, we will examine the children's answers to the questions regarding external body parts. Finally, we discuss children's explicit appeals to the goal of maintaining life.

2.3. Circulatory System

<u>2.3.1. Heart.</u>

Location. The location of the heart in children's drawings was coded into three categories: (a) abdomen; (b) chest-side; and (c) *chest-center[9]. Table 2.1 shows the percentage of children at each age locating the heart in each of these locations. For purposes of analysis, a chi-square was performed on the number of children at each age locating the heart correctly (in the center of the

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[9] * indicates "correct" location.

chest) versus incorrectly. There was no significant difference between ages ($p > .94$). At all ages, approximately half of the children seemed to know that the heart is located in the center of the chest area. In addition, a common misconception was that the heart is located clearly to one side of the chest, rather than in the middle. One plausible source for this error may be the misleading practice in American schools of placing the hand on the left side of the chest -- "over the heart" -- while saying the Pledge of Allegiance each morning.

Table 2.1. Percent of children at each age locating the heart in each area.

	Four	Six	Eight	Ten
abdomen	25	8	0	0
*chest - center	58	50	50	46
chest - side	17	42	50	54

Comparisons between these data and the results from previous studies are difficult, largely due to differences in coding and age grouping. For example, Gellert (1962) coded the heart as correctly placed if children drew it in the center or left side of the chest area. Using these criteria, she found that 60% of her youngest subjects (ages 4-6) placed the heart correctly. For comparison, 54% of our 4- to 6-year-olds placed the heart in the center of the chest, and an additional 29% placed the heart on one or the other side of the chest[10]. The only other study which asked about heart location (Smith, 1977) reported that 75% of 9- to 11-year-olds drew the heart "correctly," but gave no indication of what "correctly" might mean. Thus, as nearly as we can tell, our results seem to be in general agreement with previous findings.

Function. Children's answers to the questions "what is the heart for?" and "what would happen if someone didn't have a heart?" were ordered with respect to the following coding scheme (See Appendix A for examples of children's responses at each level.):

[10] We did not differentiate between the right and left sides of the drawings (as Gellert did) because it is unclear which sides children viewed as "right" and "left".

Level 4: Pump blood

Level 3: Other functions having to do with blood (e.g., cleaning blood)

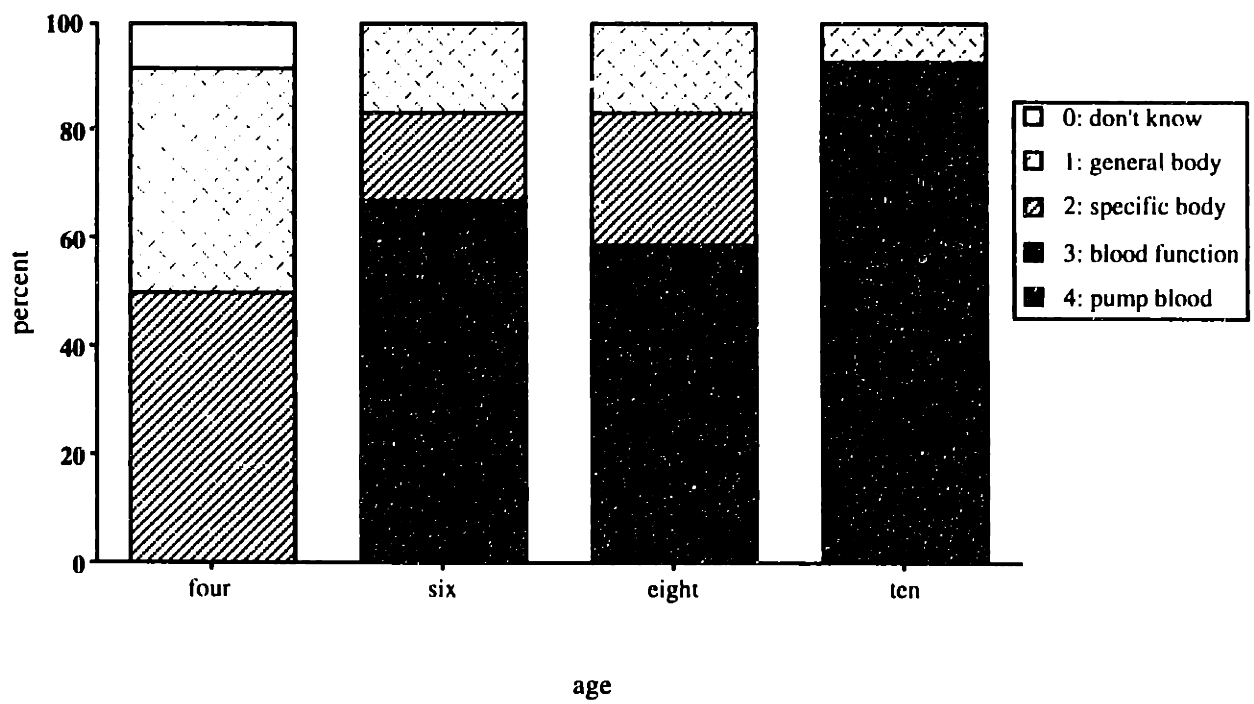
Level 2: Specific body function (e.g., breathing; activating things; psychological functions)

Level 1: General body function (e.g., for life, health, the body)

Level 0: Don't know; beating

Figure 2.1 shows the percentage of children at each age giving each level of explanation. Note that the bars on the graph are arranged to proceed from lightest for the lowest score ("don't know") to darkest for the highest score ("pumps blood"). As assessed by a one-way Kruskall-Wallis analysis of variance (corrected for ties), there was a significant difference between ages on the level of explanation given, $H(3) = 19.87$, $p < .001$. Specifically, follow-up Mann-Whitney U tests (corrected for ties) found a significant difference between the 4- and 6-year-olds, $Z = -2.94$, $p < .01$, but not between 6- and 8-year-olds ($p > .92$), nor between 8- and 10-year-olds (although this difference did approach significance [$p < .08$]).

Figure 2.1. HEART -- percent of children at each level of explanation



As shown in Figure 2.1, no 4-year-old children related the heart to blood (Levels 3 and 4). In contrast, over half of the 6- and 8-year-olds, and almost all of the 10-year-olds, related the heart's function to blood in some way, although it wasn't until age 10 that the majority of children provided the target answer that the heart "pumps blood".

As with heart location, we again have difficulties comparing these results to those of previous studies because of coding differences. Gellert (1962) categorized children's explanations of heart function into 14 categories, with each child's response falling into one or more of these categories. Because these categories were neither mutually exclusive nor hierarchically organized, it is exceptionally difficult to compare the whole of her data with ours. However, three of her categories related the heart to blood in some fashion: (1) *Function related to blood, but without concept of circulation*; (2) *Heart is essential to life: explanation includes mention of pumping and/or circulation, or blood or oxygen*; and (3) *Heart pumps blood, circulates blood, makes blood go*. If we sum across these three categories, we see that 37% of her 4 - 6-year-olds, 32% of her 7 - 8-year-olds, and 86% of her 9 - 10-year-olds related the heart to blood in some way[11]. Our current results seem to indicate a higher level of knowledge in children, at least at ages 6 and 8 (where approximately 62% of the children related the heart to blood). More importantly, however, the fact that Gellert collapsed 4- and 6-year-olds into a single age group perhaps obscures the significant increase in knowledge about the heart that the current results show between these two ages.

Other studies with older children seem to be more or less in agreement with our findings for older children. Smith (1977) found that 64% of 9- to 11-year-olds gave the correct heart function -- presumably "pumping blood". In the current study, 68% of the 8- to 10-year-olds ascribed this function to the heart. Arnaudin and Mintzes (1985) found that approximately 88% of fifth grade children (ages approximately 10 - 11) know that the heart pumps blood, while another small percentage (approximately 5%) know that the heart is related to blood. Quiggin (1977) also found that approximately 90% of 10- to 11-year-olds knew that the heart pumps blood. These

[11] Given that her categories were not mutually exclusive, this summing across categories is not fully justified. However, this at least gives us an upper limit to the number of children who related the heart to blood.

results are nearly identical with our own findings for our oldest age group.

2.3.2. Blood.

Location. The location of blood was coded from both the children's drawings and verbal responses (e.g., "It's all over") into four categories: (a) don't know; (b) localized in a particular bodily area; (c) *everywhere; and (d) *in veins. Table 2.2 shows the percentage of children at each age locating the blood in each of these locations. For purposes of analysis, a chi-square was performed on the number of children at each age locating the blood correctly (in the veins or everywhere) versus incorrectly. There was a significant difference between ages, χ^2 (3) = 29.75, $p < .001$. Specifically, there was a significant difference between the 4- and 6-year-olds, χ^2 (1) = 10.97, $p < .001$, a marginally significant difference between the 6- and 8-year-olds, χ^2 (1) = 3.43, $p < .07$, and no significant differences between the 8- and 10-year-olds ($p > .33$). At age 4, 83% of the children localized the blood in a particular location, while only 8% said that blood was everywhere (and none reported that it was in veins). In contrast, at age 6, 75% of the children reported that blood was everywhere or in veins, while fewer than 10% said that blood was localized in a particular area. At ages 8 and 10, virtually all children reported that blood was everywhere or in veins.

Table 2.2. Percent of children at each age locating blood in each area.

	Four	Six	Eight	Ten
don't know	8	17	0	0
localized	83	8	0	8
*everywhere	8	58	75	77
*veins	0	17	25	15

In light of the above result, however, it is important to mention the ambiguity inherent in the "localized" coding category. In most of the instances where this was coded, the child had simply scribbled a small area somewhere within the body outline. In contrast, when the category "everywhere" was coded, this was most often expressed verbally by the child (e.g., "everywhere"; "all over"). Given this confound of response mode with response category, one cannot rule out the possibility that these response mode differences are truly to blame for many of the apparent response type differences. For example, it is possible that the children who drew the blood rather than gave verbal responses also believed that blood was everywhere, but didn't feel the need to draw in "all" the blood.

As was the case with heart location and function, comparisons to other studies are difficult due to coding ambiguities in previous studies. Smith (1977) reported that 64% of 9- to 11-year-olds drew the blood "correctly," but gave no indication of what was coded as a correct response. No other studies have reported data regarding children's knowledge of blood location.

Function. Children's answers to the questions "what is the blood for?" and "what would happen if someone didn't have any blood?" were ordered with respect to the following coding scheme (See Appendix B for examples of children's responses at each level.):

Level 3: Transport air and/or food; attack germs

Level 2: Specific body function (e.g., for strength, moving, to activate body parts)

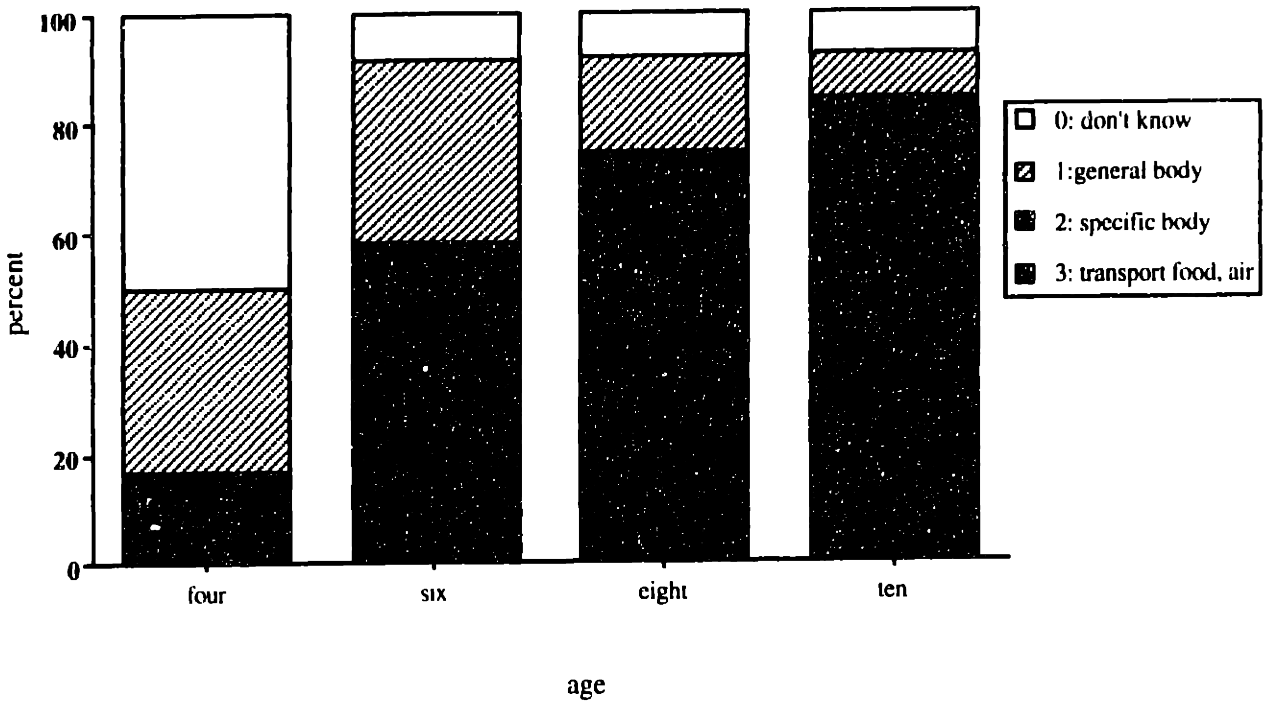
Level 1: General body function (e.g., for the body, life)

Level 0: Don't know; tautology (e.g., for bleeding)

Figure 2.2 shows the percentage of children at each age giving each level of explanation. As before, the bars on the graph are arranged to proceed from lightest for the lowest-level explanation to darkest for the highest-level explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data revealed a significant difference between ages on the level of explanation given, $H(3) = 14.05, p < .01$. Follow-up Mann-Whitney U tests (corrected for ties) revealed a significant difference between 4- and 6-year-olds, $Z = -2.58, p < .01$, but no significant differences between 6- and 8-year-olds ($p > .36$), nor between 8- and 10-year-olds ($p >$

.49).

Figure 2.2. BLOOD -- percent of children at each level of explanation



As shown in Figure 2.2, no 4-year-old children explained the function of the blood in terms of transporting material to different parts of the body. Instead, fully half of the 4-year-olds gave "don't know" or tautological responses (e.g., "It's for bleeding"), while an additional 30% suggested general body functions (e.g., for life; for health) [Level 1]. In contrast, the majority of 6-, 8-, and 10-year-olds suggested a specific body function or provided the target response that the blood transports food or air. However, at no age was the highest level of explanation attained by the majority of the children. This is consistent with Smith (1977), who found that only 20% of 9- to 11-year-olds "had even the vaguest notion that [blood] somehow supplied food, energy, or nourishment" (p. 1966).

2.3.3. Discussion for Circulatory System.

In summary, the results of the current study are in general agreement with previous findings regarding children's knowledge of the circulatory system. In addition, however, our results suggest a previously unnoticed shift in children's explanations of organ function between 4 and 6 years of age. In children's explanations of both heart function and blood function, we found a significant difference in explanation level between 4- and 6-year olds, but not between 6- and 8-year-olds, or between 8- and 10-year-olds. It is important to point out, however, that this shift is not simply from "not knowing" to "knowing" the correct canonical function. At age 6, only 42% of the children knew that the heart pumps blood, and only 25% knew that blood transports materials throughout the body. Rather, the increase seems to be in <u>level of explanation</u> for bodily function (i.e., from more general to more specific explanations), even if the more specific explanations are incorrect.

With respect to children's knowledge of organ location, the evidence for a similar age shift is not at all clear. We did find a significant shift between 4- and 6-year-olds in their reporting of blood location. However, due to the ambiguities stemming from differences in the children's response modes (i.e., drawing versus verbal), it is uncertain whether this shift was indicative of an actual shift in knowledge. There was no such age shift with respect to children's knowledge of heart location.

2.4. Respiratory System

<u>2.4.1. Lungs.</u>

Location . The location of the lungs in children's drawings were coded into five categories: (a) don't know; (b) limbs; (c) neck or mouth; (d) abdomen; and (e) *chest. Table 2.3 shows the percentage of children at each age locating the lungs in each of these locations. For purposes of analysis, a chi-square was performed on the number of children at each age locating the lungs correctly (in the chest) versus incorrectly. There was a significant difference between ages, χ^2 (3) = 13.26, $p < .01$. Specifically, there was a significant difference between 4- and 6-year-olds, χ^2 (1) = 8.22, $p < .01$, but no significant differences between 6- and 8-year-olds ($p > .61$), nor between 8- and 10-year-olds ($p > .54$). This pattern can presumably be explained by the fact that

50% of the 4-year-olds said they didn't know where the lungs were, while only 25% placed them correctly in the chest area. In contrast, over 75% of the 6- to 10-year-olds placed the lungs correctly in the chest area, while only one 8-year-old (and none of the 6- or 10-year-olds) said she didn't know where the lungs were located.

Table 2.3. Percent of children at each age locating the lungs in each area.

	Four	Six	Eight	Ten
don't know	50	0	8	0
limbs	17	0	0	0
neck / mouth	8	17	17	15
abdomen	0	8	0	0
*chest	25	75	75	85

Given the summary-type nature of most previous studies, it is difficult to tell how representative our results are. One popular misconception among children seems to be that the lungs are located in the head or neck area. Nagy (1953) reports that "nearly half" of the 5- to 11-year-old children in her study located the lungs in the head or neck. In Gellert's (1962) study, 21% of her 4- to 6-year-olds, 38% of her 7- to 8-year-olds, and approximately 45% of her 9- to 10-year-olds located the lungs in the head or neck area. In the current study, we also find this misconception, but at a much smaller rate (approximately 8-17% at all ages).

As for "correct" location, Quiggin (1977) reports that the "majority" of children in her study (ages 10 - 11) drew the lungs in the correct position. She does not, however, report how stringent her criteria were for "correctness". Gellert (1962) reports that 32% - 44% of the children in each age group located the lungs correctly in the chest. Our current results show a greater knowledge of lung location at all ages, with the possible exception of 4-year-olds. However, because Gellert grouped 4- and 6-year-olds in the same age group, we have no way of knowing whether the shift between those age groups shown in the current results was also represented in Gellert's data.

Function. Children's answers to the questions "what are the lungs for?" and "what would happen if someone didn't have any lungs?" were ordered with respect to the following coding scheme (See Appendix C for examples of children's responses at each level.):

Level 4: Air intake (e.g., breathing air)

Level 3: Breathing as activity (i.e., no mention of air)

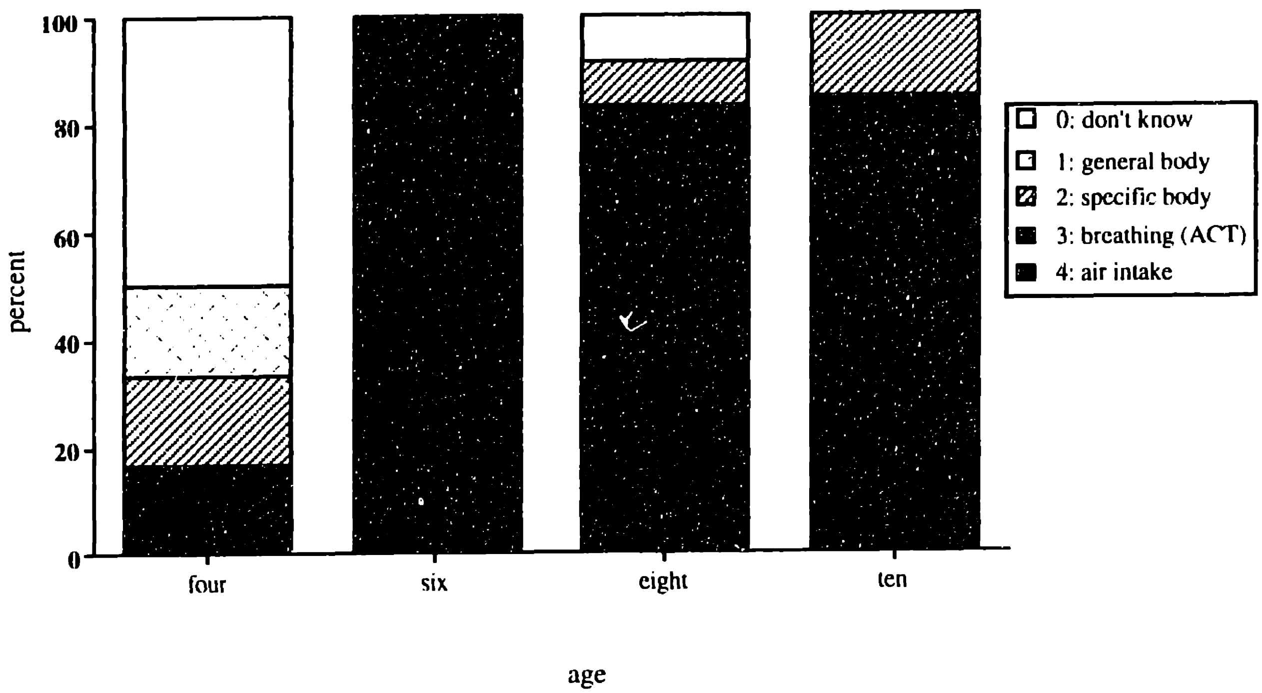
Level 2: Specific body function (e.g., protection, moving)

Level 1: General body function (e.g., for the body; life)

Level 0: Don't know

Figure 2.3 shows the percentage of children at each age expressing each level of explanation. As before, the bars on the graph are arranged to proceed from lightest for the lowest-level explanation to darkest for the highest-level explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data showed a significant difference between ages on the level of explanation expressed, H (3) = 21.29, $p < .001$. Follow-up Mann-Whitney U tests (corrected for ties) revealed a significant difference between 4- and 6-year-olds, $Z = -3.88$, $p < .001$, but no significant differences between 6- and 8-year-olds ($p > .93$), nor between 8- and 10-year-olds ($p > .52$).

Figure 2.3. LUNGS -- percent of children at each level of explanation



As shown in Figure 2.3, half of the 4-year-old children simply said they didn't know what lungs were for, and less than 20% even connected lungs to the act of breathing. In contrast, at age 6, the predominant (and almost exclusive) response was that lungs were "for breathing". As the children got older, this continued to be a dominant response, but in addition many children began to connect lungs (and therefore presumably "breathing") to the actual intake of air.

In previous studies, no distinction was made between breathing as a behavior or activity, and breathing as involving the intake of air. In Nagy's (1953) study, 74% of children ages 5 to 11 explained the function of the lungs in terms of breathing. Again, however, she gives no age breakdown of her data. Gellert (1962) reports that only 7% of her 4 - 6-year-olds, 33% of her 7 - 8-year-olds, and 65% of her 9 - 10-year-olds explained lung function in terms of air intake or breathing. This response corresponds to levels 3 and 4 combined in the current study. Our current results seem to indicate a higher level of knowledge at all ages (58% of our 4 - 6-year-olds, and

84% of our 8 - 10-year-olds connected the lungs to the act of breathing or air intake). As before, the fact that Gellert collapsed 4- and 6-year-olds into a single age group perhaps obscures the large shift in knowledge about the lungs that the results of the current study show between these two ages.

2.4.2. Air.

Why we breathe it. Children's answers to the question "Why do we breathe air?" were coded into four categories: (a) don't know; (b) necessity (e.g., *we have to*); (c) social / global (e.g., *the world needs it*; *so we could talk*); and (d) Life / body function (e.g., *so that it can go to the heart and the heart can produce more blood*) (see Table 2.4). For purposes of analysis, a chi-square was performed on the number of children at each age explaining breathing in terms of Life or a body function versus other responses. There was no significant difference between ages ($p >$ .14). When we examine the table, however, we do see a slight suggestive age trend, in that over half of the 4-year-olds simply don't know why we breathe air, while over half of the 6-, 8-, and 10-year-olds attribute its function to keeping us alive or performing some bodily function.

Table 2.4. Percent of children at each age giving each explanation for why we breathe air.

	Four	Six	Eight	Ten
don't know	59	25	25	15
necessity	8	8	8	15
social / global	8	8	8	0
Life / body function	25	58	58	69

In the only other study to ask why we breathe air, Nagy (1953) also found a large proportion the children between that ages of 4 and 11 asserting that it was necessary for life. However, since she doesn't provide any age breakdowns, we have no way of knowing whether there were any shifts in explanations over the different ages she tested.

What happens to it? Children's answers to the question "what happens to the air that we breathe?" were coded into 4 categories: (a) don't know; (b) it goes in and out; (c) it goes along a particular path in the body; and (d) it is transformed into something. These were ordered into the following levels (cf. Perrin, Sayer, & Willett, 1991):

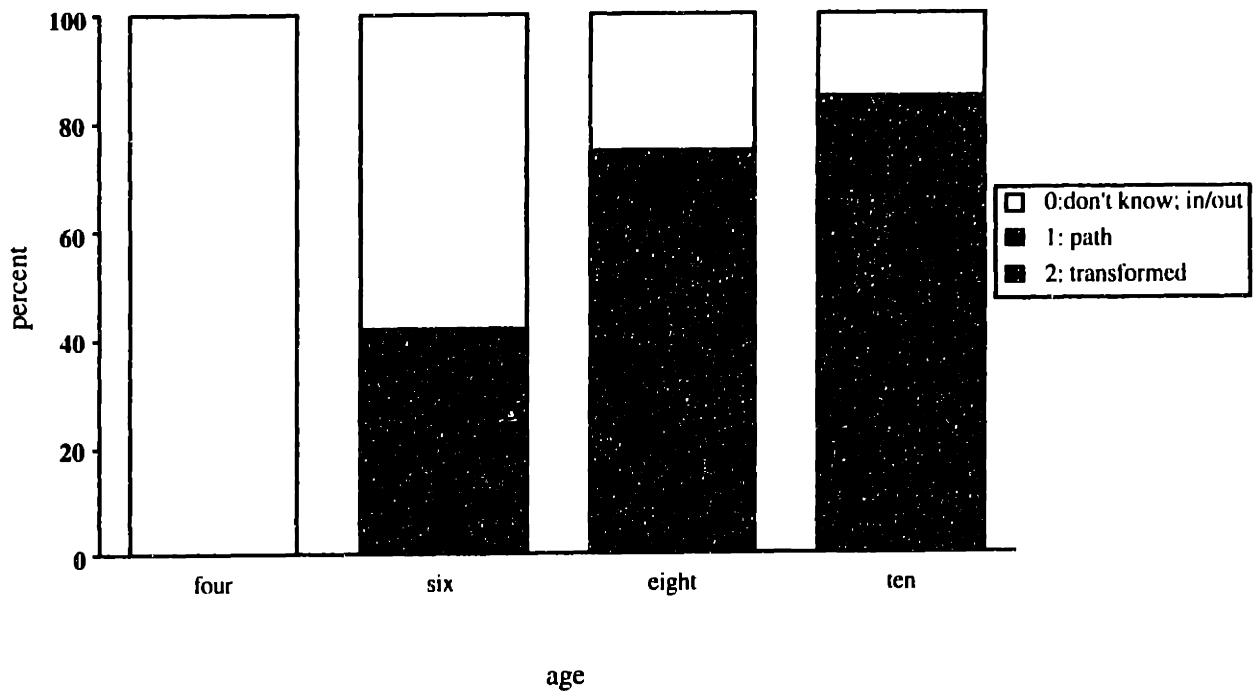
Level 2: transformed

Level 1: path

Level 0: don't know; in & out

Each child was credited with the highest level explanation she gave. Figure 2.4 shows the percentage of children at each age giving each level of explanation. As before, the bars on the graph are arranged to proceed from lightest for the lowest-level explanation to darkest for the highest-level explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) performed on these data revealed a significant difference between ages in the level of explanation given, $H(3) = 17.13$, $p < .001$. Follow-up Mann-Whitney U analyses (corrected for ties) revealed a significant difference in explanation level between 4- and 6-year-olds, $Z = -2.44$, $p < .02$, but not between 6- and 8-year-olds ($p > .20$), nor between 8- and 10-year-olds ($p > .73$).

Figure 2.4. "WHAT HAPPENS TO THE AIR THAT WE BREATHE?"
Percent of children at each level of explanation



As shown in Figure 2.4, all of the 4-year-olds said either that they didn't know what happens to the air, or that it simply goes in and out. By age 6, 40% of the children gave some path through the body, and/or said that the air was transformed within the body (e.g., "it turns into carbon dioxide"). Responses which delineated some path within the body increased as children got older, although the idea that the air gets transformed remained low across all age groups. This is consistent with Nagy (1953), who found that "the majority of the children [ages 4 - 11] thought respiration to consist in a movement of the air in and out or up and down, without any reference to change" (p. 208).

2.4.3. Summary for Respiratory System.

Children's knowledge about the components of the respiratory system appears to undergo a significant shift between 4 and 6 years of age. In children's explanations of lung location, lung function, and what happens to the air that we breathe, there was a significant difference between 4- and 6-year olds, but not between 6- and 8-year-olds, or between 8- and 10-year-olds. This shift has not been reported in previous literature, perhaps because previous results did not delineate responses according to age (e.g., Nagy, 1953), or because the age grouping of previous studies makes it impossible to observe such a shift (e.g., Gellert's [1962] study, in which 4- to 6-year-olds were considered a single age group). It is important to point out that this apparent shift cannot be explained as one from simply "not knowing" to "knowing" the correct canonical information. For example, at age 6, only 8% of the children knew that the lungs were connected with the intake of air, and only 25% appeared to know that air is transformed somehow within the body.

2.5. Digestive System

2.5.1. Stomach.

Location. The location of the stomach in children's drawings was coded into 3 categories: (a) *an organ in the chest or abdomen area; (b) stomach as the mid-torso region[12]; and (c) other (e.g., leg, throat, shoulder). Table 2.5 shows the percentage of children at each age locating the stomach in each of these locations. For purposes of analysis, a chi-square was performed on the number of children at each age locating the stomach correctly versus incorrectly. There was no significant difference between ages ($p > .31$).

Table 2.5 Percent of children at each age locating the stomach in each area.

	Four	Six	Eight	Ten
*chest / abdomen	58	42	50	77
stomach = mid-torso	17	50	50	23
other	25	8	0	0

[12] Given the ambiguity of both the word "stomach" and the children's drawings, it was not possible to determine whether the children were referring to the external "belly" area, or to the entire internal torso cavity. Children's responses were coded as belonging to this category when the stomach region in their drawing extended to or beyond the outlines of the body.

Given the summary-type nature of most previous studies, and the differences in coding and age grouping, comparisons to previous studies are not particularly illuminating. Nagy (1953) credits 47% of children between the ages of 4 - 11 with locating the stomach as an organ in the abdomen or chest. Gellert (1962) credits 87% of children between the ages of 4 - 10 with this knowledge. Our own results (57%) fall between these two endpoints.

It is interesting to note that in the current study, fully half of the children at ages 6 and 8 located the stomach as the entire mid-torso region (perhaps due to the ambiguity of the word in the English language). Hints of this phenomenon can also be found in previous studies, though perhaps to a lesser degree. Smith (1977) states that "the stomach was often considered to be an area of the body rather than a distinct organ" (p. 1967), but she gives no specific details about how common this was. Gellert (1962) reports that 13% of children ages 4 - 10 located the stomach as occupying "almost [the] entire trunk area" (compared with 35% in the current study). However, she does not report any data regarding differences between specific ages within this large age bracket.

Function. Children's answers to the questions "what is the stomach for?" and "what would happen if someone didn't have a stomach?" were ordered with respect to the following coding scheme (See Appendix D for examples of children's responses at each level.):

Level 4: Digestion

Level 3: Food container; eating; nourishment

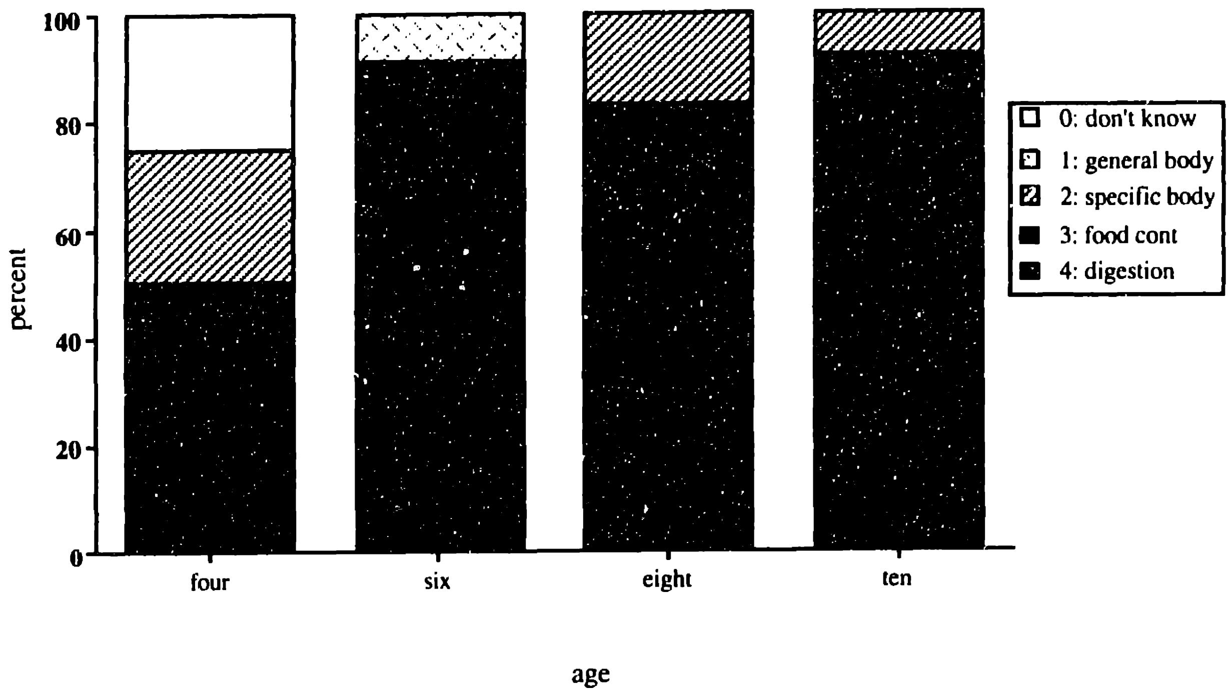
Level 2: Specific body function (e.g., breathing; moving; organ container)

Level 1: General body function (e.g., for life)

Level 0: Don't know; stomach-ache

Figure 2.5 shows the percentage of children at each age giving each level of explanation. As before, the bars on the graph are arranged to proceed from lightest for the lowest-level explanation to darkest for the highest-level explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data showed a significant difference between ages in the level of explanation given, $H(3) = 12.58, p < .01$. Specifically, Mann-Whitney U analyses (corrected for ties) revealed that there was a significant difference in explanation level between the 4- and 6-year-olds, $Z = -2.66, p < .01$, but not between the 6- and 8-year-olds ($p > .39$), nor between the 8- and 10-year-olds ($p > .23$).

Figure 2.5. STOMACH -- percent of children at each level of explanation



As shown in Figure 2.5, half of the 4-year-old children did not connect the stomach with having any relation to food (Levels 0 - 2). In contrast, by age 6, nearly all of the children knew that the stomach had some relation to food (levels 3 and 4). Many of the 6- to 10-year-olds, however, simply knew that the stomach "holds" food, and did not realize that it also processes it in some way.

Results of previous studies seem to be in general agreement with the current results. In Nagy's (1953) study, 69% of children ages 5 - 11 said the stomach was for eating or storing food (comparable to our Level 3), while 15% said the stomach was for digestion (comparable to our

Level 4). The children in the current study perhaps show a bit more knowledge that the stomach is involved in digestion (51% at Level 3; 29% at Level 4). However, as Nagy gives no age breakdown, we cannot know whether her age trends would be similar to our own.

Gellert (1962) categorized children's explanations of stomach function into 11 categories, with each child's response falling into one or more categories. Because these categories were neither mutually exclusive nor hierarchically organized, it is difficult to compare the whole of her data with ours. However, two of her categories seem to map rather straightforwardly onto our own: (1) *Function related to any aspect of digestion* [our Level 4]; and (2) *Function related to food and/or eating* [our Levels 3 + 4]. Table 2.6 presents a comparison of Gellert's data to our own, re-analyzed to fit her categories.

Table 2.6. Percent of children giving each explanation of stomach function.

Gellert (1962)				Current Study			
Ages	4-6	7-8	9-10	Ages	4-6	8	10
food/eating	70	95	96	Levels 3 + 4	71	83	92
digestion	--	21	30	Level 4	17	58	23

As shown in Table 2.6, our results seem to be in general agreement with Gellert's data, although again with the exception that more of the younger children in the current study mentioned digestion. More importantly, however, the fact that Gellert collapsed 4- and 6-year-olds into a single age group again perhaps obscures the significant increase in knowledge about the stomach that the current study shows between these two ages.

2.5.2. Food.

Why we eat it. Children's answers to the question "Why do we eat food?" were coded into 6 categories: (a) don't know; (b) hunger; (c) substance (e.g., *so you can grow*; *so you don't get skinny*); (d) energy; (e) general health and strength; and (f) Life (see Table 2.7). Because some children gave more than one type of response, statistics on these data were not feasible. However, from examining the table, we find a shift in the predominant response from food providing health and strength at age 4 (67%) to food being necessary for life at ages 6 - 10 (42% - 75%).

Table 2.7. Percent of children at each age giving each explanation for why we eat food.

	Four	Six	Eight	Ten
don't know	--	8	--	--
hunger	8	8	--	8
substance	25	8	25	23
energy	--	17	8	15
health/strength	67	25	17	46
Life	--	42	75	62

What happens to it? Children's answers to the question "What happens to the food that we eat?" were ordered with respect to the following coding scheme:

Level 3: (a) goes to other body parts after stomach; (b) some stays in body, some goes out.

Level 2: goes through body and out

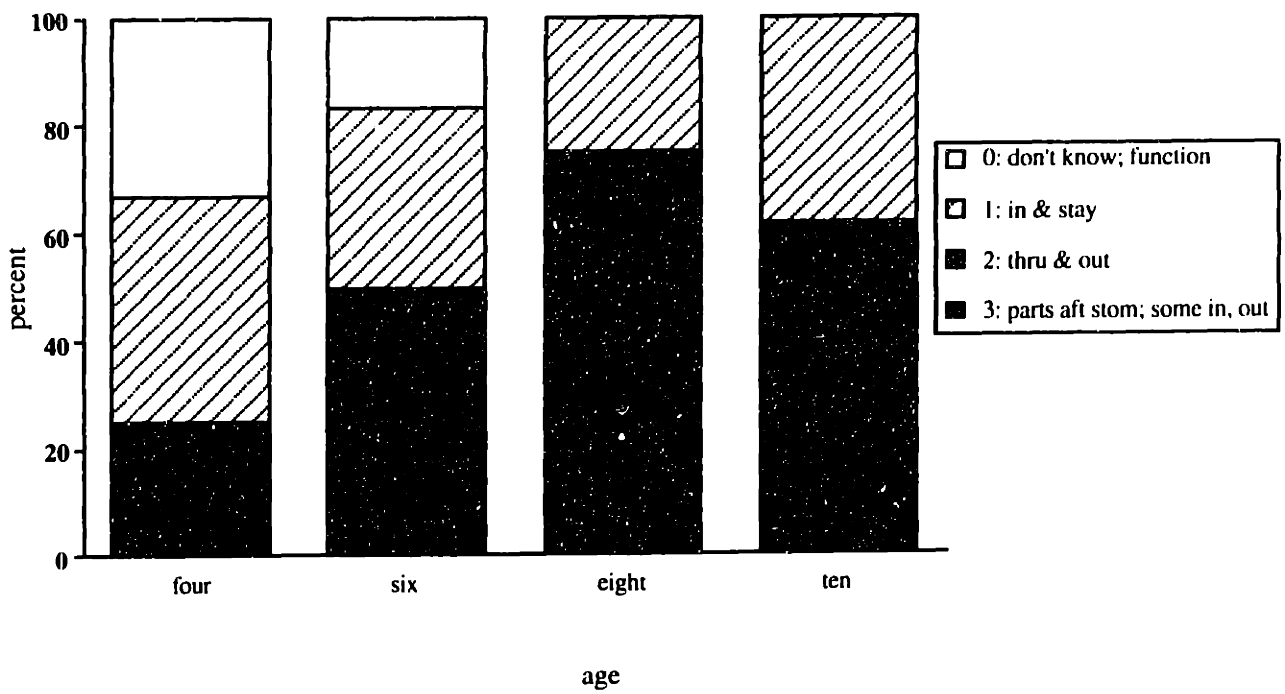
Level 1: goes into body or stomach and either stays or "disappears" [note: includes "digest" when not explained]

Level 0: don't know; re-assertion of bodily function (e.g., growth; strength)

Children were credited with the highest level of explanation they expressed.

Figure 2.6 shows the percentage of children at each age giving each level of explanation. As before, the bars on the graph are arranged to proceed from lightest for the lowest-level explanation to darkest for the highest-level explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data revealed a significant difference between ages on the level of explanation given, $H(3) = 9.48, p < .03$. Follow-up Mann-Whitney U tests (corrected for ties), however, revealed no significant differences between any two consecutive age groups.

Figure 2.6. "WHAT HAPPENS TO THE FOOD THAT WE EAT?"
Percent of children at each level of explanation



Although there were no dramatic shifts between any consecutive age groups, it is interesting to note that two ideas about the path of food in the body were not present in the youngest subjects: (1) that the food is distributed to different parts of the body after the stomach; and (2) that some of the food is used by the body while some is eliminated. In Gellert's (1962) data, approximately 35-38% of her youngest children expressed at least one of these ideas. However, in her analysis of this question, she included 4- to 7-year-olds as a single age group. Thus we again have no way of knowing whether this pattern for 4-year-olds is idiosyncratic to our data, or whether it might have been found in hers as well.

2.5.3. Summary for Digestive System.

In summary, the results of the current study are comparable with previous findings regarding children's knowledge of the digestive system. In addition, however, we again find a previously unnoticed shift in some aspects of children's knowledge between 4 and 6 years of age. In children's explanations of stomach function, there was a significant difference in explanation level between 4- and 6-year olds, but not between 6- and 8-year-olds, or between 8- and 10-year-olds. Moreover, although we could not legitimize this finding with statistical tests, we found a suggestive difference in explanations at different ages for why we eat food, with the idea that food is necessary to keep us alive not emerging until age 6.

This knowledge shift between ages 4 and 6 did not extend to all components of the digestive system, however. Specifically, there were no significant differences between ages either in knowledge of what happens to the food we eat or where the stomach is located.

2.6. Nervous System

2.6.1. Brain.

Location. The location of the brain in children's drawings was coded into three categories: (a) don't know; (b) arm or abdomen; (c) *head. Table 2.8 shows the percentage of children at each age placing the brain into each of these locations. For purposes of analysis, a chi-square was performed on the number of children at each age locating the brain correctly (in the head) versus incorrectly. There was a significant difference between ages, χ^2 (3) = 21.08, $p < .001$. Specifically, there was a significant difference between the 4- and 6-year-olds, χ^2 (1) = 8.00, $p < .01$, but no differences between the 6-, 8-, and 10-year-olds.

Table 2.8. Percent of children at each age locating the brain in each area.

	Four	Six	Eight	Ten
don't know	25	0	0	0
arm / abdomen	25	0	0	0
*head	50	100	100	100

From the table we can see this developmental progression clearly, in that 50% of the 4-

year-olds either said they didn't know where the brain was located, or placed the brain in an inappropriate place; whereas all of the 6-, 8-, and 10-year-olds located the brain correctly in the head. A similar progression was found by Johnson and Wellman (1982), in which 47% of 3-year-olds, 81% of 4-year-olds, and 100% of 5-year-olds located the brain correctly in the head.

Function. Children's answers to the questions "what is the brain for?" and "what would happen if someone didn't have a brain?" were ordered with respect to the following coding scheme (See Appendix E for examples of children's responses at each level.):

Level 4: Specific control (e.g., send messages; moving; seeing; talking)

Level 3: Thinking; Cognitive function

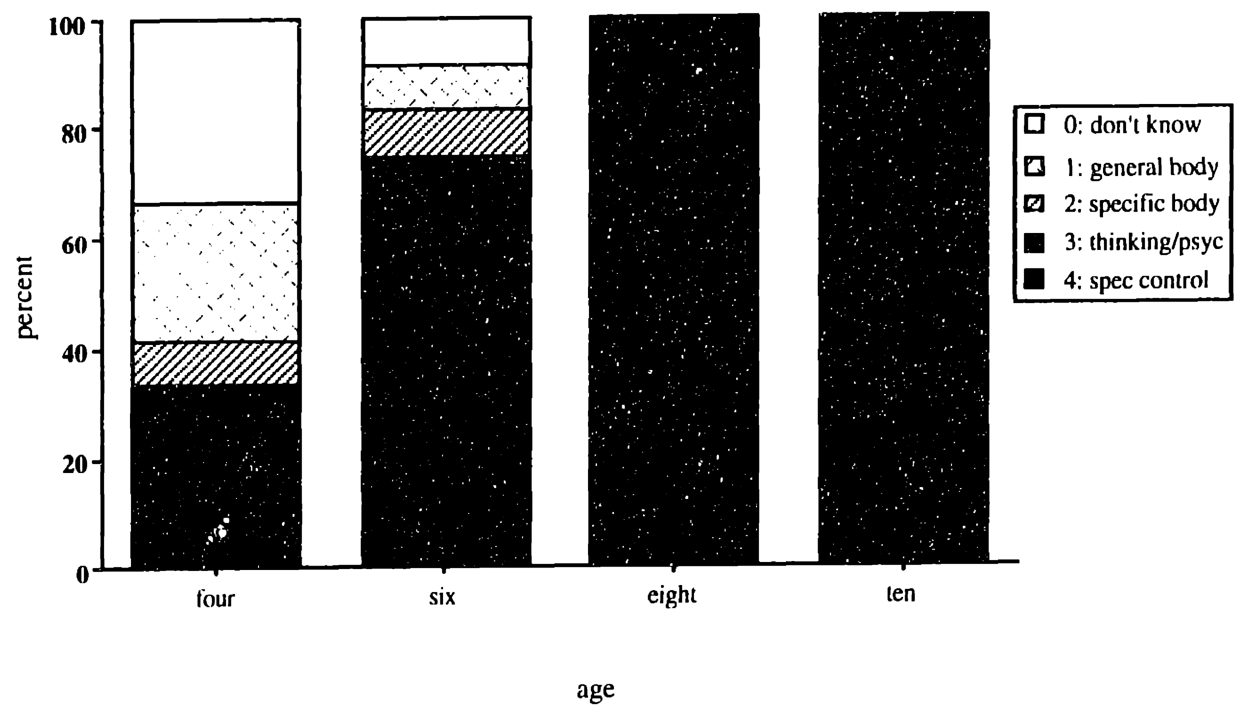
Level 2: Specific body function (e.g., hardness; activate things)

Level 1: General body function (e.g., for the body, life)

Level 0: Don't know; headache

Figure 2.7 shows the percentage of children at each age giving each level of explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data revealed a significant difference between ages in the level of explanation expressed, $H(3) = 29.11$, $p < .001$. Follow-up Mann-Whitney U analyses (corrected for ties) revealed significant differences between both the 4- and 6-year-olds, $Z = -2.18$, $p < .03$, and the 6- and 8-year-olds, $Z = -2.55$, $p < .02$, but not between the 8- and 10-year-olds (although this difference did approach significance, $p < .07$).

Figure 2.7. BRAIN -- percent of children at each level of explanation



As shown in Figure 2.7, over half of the 4-year-old children either said they didn't know what the brain was for, or said it was for some sort of general body function. By age 6, the predominant response was that the brain is for thinking. Between ages 6 and 8, there was a growing realization that, in addition to such global mental functions, the brain is also the actual control center for the various functions of the body. This realization continued to increase between the ages of 8 and 10.

A suggestion of both of these shifts can also be found in Johnson and Wellman (1982). In that study, they questioned children about what specific activities require a brain. When they asked young children if you need your brain "to think", only 64% of 4-year-olds, but 100% of 5-year-olds answered affirmatively (perhaps comparable to the 4-to-6 shift in the current study). In addition, when they asked older children to make judgments about whether the brain was needed to perform a variety of activities, kindergartners (ages 5 - 6) judged that you need your brain for cognitive or intellectual tasks, but generally not for motor tasks or senses (e.g., walking, talking). With age, there was an increase in judgments that the brain was needed for these ("non-cognitive") tasks, with the biggest gain taking place between kindergartners and the next youngest age group (ages 8-9). This seems to be comparable to second shift in the current study, due to the realization that the brain controls various bodily functions.

2.6.2. Nerves.

Location. The location of the nerves was coded from both the children's drawings and verbal responses (e.g., "They're everywhere") into four categories: (a) don't know; (b) in the head; (c) localized in a particular [non-head] bodily area; and (d) *everywhere. Table 2.9 shows the percentage of children at each age locating the nerves in each of these locations. For purposes of analysis, a chi-square was performed on the number of children at each age locating the nerves correctly (everywhere) versus incorrectly. There was a significant difference between ages, χ^2 (3) = 12.94, $p < .01$. However, there were no significant differences between any two successive age groups. Rather, as shown in Table 2.9, there appears to be a gradual shift from simply not knowing where the nerves are to saying that they're everywhere.

Table 2.9. Percent of children at each age locating the nerves in each area.

	Four	Six	Eight	Ten
don't know	67	58	33	8
head	8	8	17	15
localized	25	17	8	15
*everywhere	0	17	42	62

No previous study reports systematic data regarding the children's beliefs about nerve location at different ages. However, both Gellert (1962) and Nagy (1953) report that a number of children localized nerves in the head, perhaps because they failed to distinguish between nerves and the brain (22% of the children in Gellert, and 38% in Nagy). The current study also found children localizing nerves in the head, but at a much smaller rate (12% overall).

Function. Children's answers to the questions "what are nerves for?" and "what would happen if someone didn't have nerves?" were ordered with respect to the following coding scheme (See Appendix F for examples of children's responses at each level.):

Level 4: Send messages; sensation

Level 3: Thinking; emotions (e.g., feeling nervous, scared)

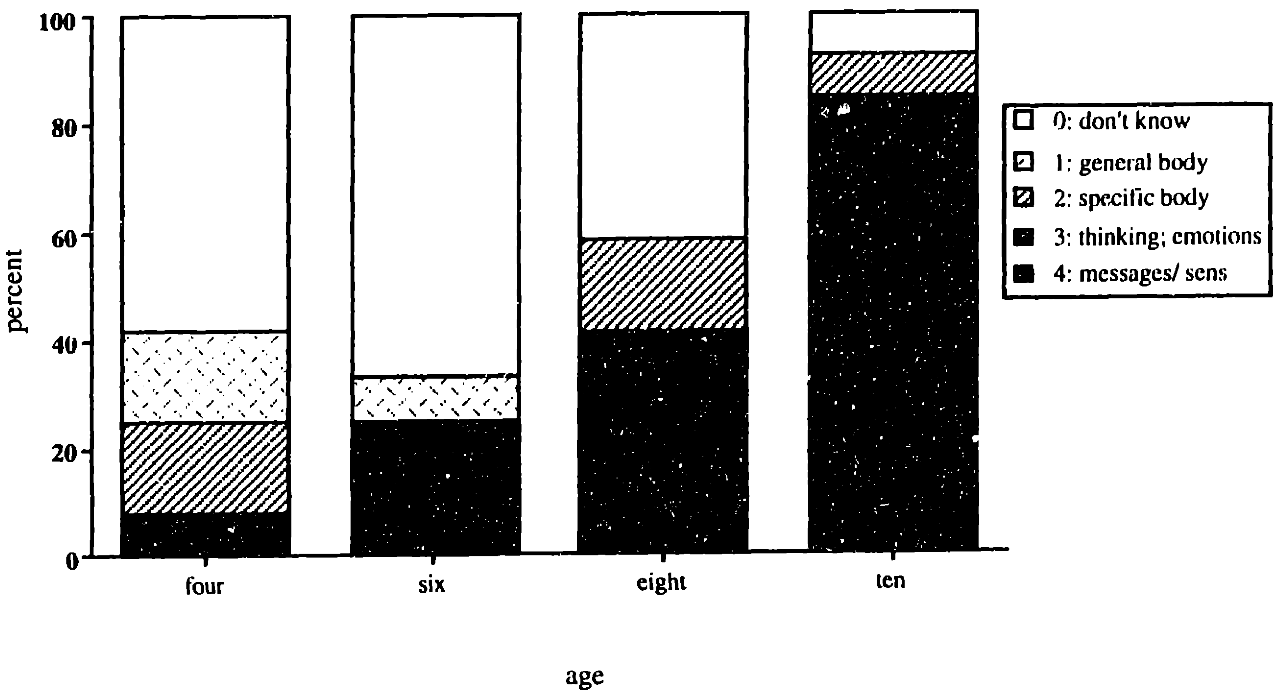
Level 2: Specific body function (e.g., moving; protection; transport food/air)

Level 1: General body function (e.g., for the body, life)

Level 0: Don't know

Figure 2.8 shows the percentage of children at each age giving each level of explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data revealed a significant difference between ages in the level of explanation expressed, $H(3) = 16.44, p < .001$. Follow-up Mann-Whitney U analyses (corrected for ties) revealed no significant differences between the 4- and 6-year-olds ($p > .97$), nor between the 6- and 8-year-olds ($p > .21$). There was, however, a significant difference between the 8- and 10-year-olds, $Z = -2.14, p < .04$.

Figure 2.8. NERVES -- percent of children at each level of explanation



Of all the body parts, the nerves were the least understood or well known by the younger children in the study. From 42 - 67% of the children at ages 4, 6, and 8 said they had either never heard of nerves, or at least didn't know what they were for (Level 0). At age 10, in contrast, over two-thirds of the children gave the target response that nerves were for sensing or sending messages. Similar results were found by Gellert (1962), who reported that before age 9, most children "did not know that they have nerves, gave irrelevant responses, or could not specify what nerves do" (p. 361). As in the current study, Gellert reported a large leap in the number of children explaining nerve function in terms of sensation between ages 7-8 (6%) and 9-10 (48%).

2.6.3. Summary for Nervous System.

In summary, the results of the current study are in general agreement with previous findings regarding children's knowledge of the nervous system. In addition, although we find a (by now characteristic) shift in children's explanations of brain function between 4 and 6 years of age, we also see later shifts in children's knowledge of both brain and nerve function. The first shift does not seem to simply be from "not knowing" to "knowing" the correct canonical function. At age 6, only 8% of the children explained the brain's function in terms of a control center for bodily functions. The second shift, however, (between ages 6 and 8 for the brain, and 8 and 10 for nerves) does seem to be explained by children having learned the "correct" canonical organ function.

With respect to the locations of the nervous system components, we also find significant differences between age groups. For brain location, this shift occurs at the 4-to-6 age boundary. For nerve location, however, there is no significant shift between any two successive age groups. Rather, we simply see gradual growth in knowledge between the ages of 4 and 10.

2.7. Musculo-Skeletal System

2.7.1. Bones

Location. The location of bones was coded from both the children's drawings and verbal responses (e.g., "They're all over.") into four categories: (a) don't know; (b) arms or legs; (c) torso; and (d) *everywhere. Table 2.10 shows the percentage of children at each age locating the bones in each of these locations. For purposes of analysis, a chi-square was performed on the number of children at each age locating the bones correctly (everywhere) versus incorrectly. There was a significant difference between ages, χ^2 (3) = 20.73, $p < .001$. Follow-up analyses revealed a significant difference between the 6- and 8-year-olds, χ^2 (1) = 6.17, $p < .02$, but not between the 4- and 6-year-olds ($p > .34$), nor between the 8- and 10-year-olds ($p > .49$). While half of the 4- and 6-year-olds localized the bones in the arms or legs, over four-fifths of the 8- and 10-year-olds said that bones are everywhere.

Table 2.10. Percent of children at each age locating the bones in each area.

	Four	Six	Eight	Ten
don't know	8	0	0	0
arms & legs	50	58	17	8
torso	25	8	0	0
*everywhere	17	33	83	92

In the only other study to discuss children's ideas of bone location, Gellert (1962) reports that children between the ages of 4 and 16 gave the most emphasis to bones in the extremities (i.e., arms and legs). The current study also shows this bias in our two youngest age groups. Gellert, however, does not report any age-related trends for these data.

Function. Children's answers to the questions "what are bones for?" and "what would happen if someone didn't have any bones?" were ordered with respect to the following coding scheme (See Appendix G for examples of children's responses at each level.):

Level 4: Structure and shape; protects organs

Level 3: Movement

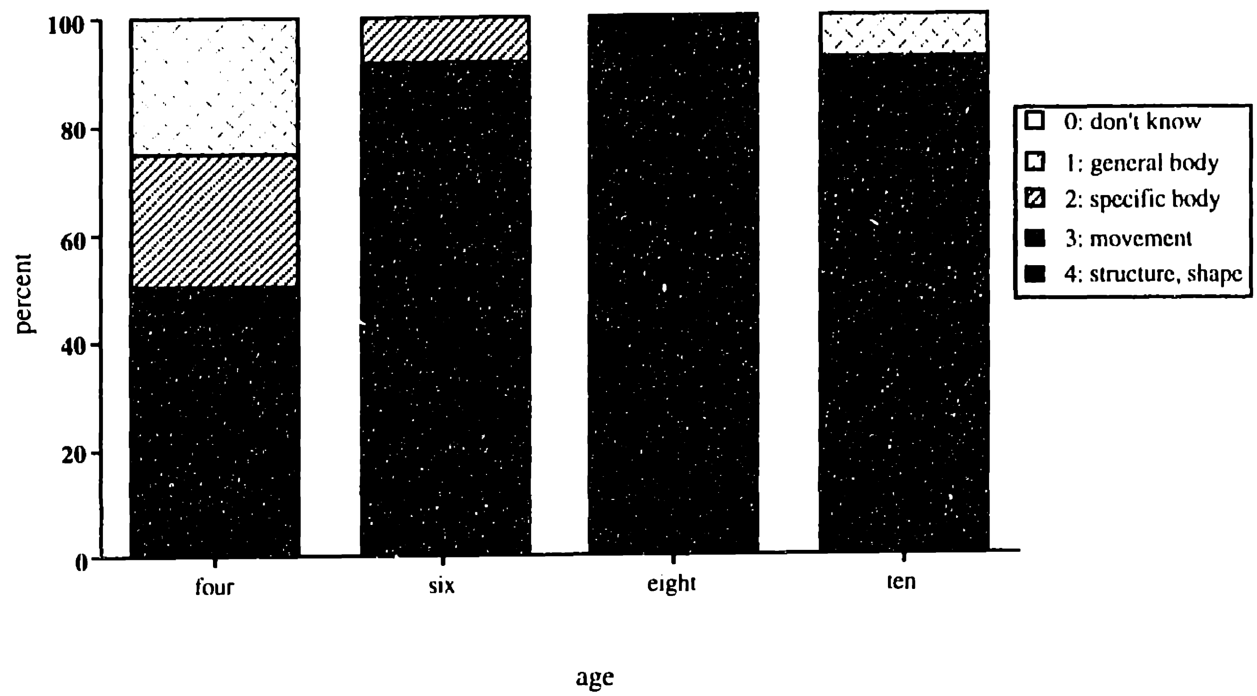
Level 2: Specific body function (e.g., for strength; food container)

Level 1: General body function (e.g., for the body, life)

Level 0: Don't know

Figure 2.9 shows the percentage of children at each age giving each level of explanation. As before, the bars on the graph are arranged to proceed from lightest for the lowest-level explanation to darkest for the highest-level explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data revealed a significant difference between ages on the level of explanation given, $H(3) = 12.16$, $p < .01$. Follow-up Mann-Whitney U tests (corrected for ties) revealed a significant difference between 4- and 6-year-olds, $Z = -2.00$, $p < .05$, but no significant differences between 6- and 8-year-olds (although this difference did approach significance; $p < .09$), nor between 8- and 10-year-olds ($p > .38$).

Figure 2.9. BONES -- percent of children at each level of explanation



As shown in Figure 2.9, half of the 4-year-old children did not connect bones with having any relation to shape, structure, or movement [Levels 3 and 4]. In contrast, at ages 6 - 10, these were the predominant (and almost exclusive) responses given by the children.

Due to the summary-type nature of previous studies, comparisons to other studies are again difficult. However, Gellert (1962) does report that overall, the most frequently mentioned bone function was "providing form, structure, and hardness" (p. 351) [our Level 4]. Moreover, as in the current study, the frequency of this explanation increased with age.

2.7.2. Muscles

Location. The location of muscles was coded from both the children's drawings and verbal responses (e.g., "They're all over.") into four categories: (a) don't know; (b) arms or legs; (c) torso; and (d) *everywhere. Table 2.11 shows the percentage of children at each age locating the muscles in each of these locations. For purposes of analysis, a chi-square was performed on the number of children at each age locating the muscles correctly (everywhere) versus incorrectly. There was a significant difference between ages, χ^2 (3) = 9.49, $p < .03$. Follow-up analyses revealed a significant difference between the 6- and 8-year-olds, χ^2 (1) = 5.04, $p < .03$, but not between the 4- and 6-year-olds ($p > .99$), nor between the 8- and 10-year-olds ($p > .84$). At ages 4 and 6, less than 10% of the children located the muscles throughout the entire body. Rather, over 75% located them exclusively in the arms and legs. At ages 8 and 10, in contrast, approximately half of the children located the muscles throughout the body, although arms and legs continued to be a popular response (approximately 44%)

Table 2.11. Percent of children at each age locating the muscles in each area.

	Four	Six	Eight	Ten
don't know	0	8	0	8
arms & legs	83	75	42	46
torso	8	8	8	0
*everywhere	8	8	50	46

Function. Children's answers to the questions "what are muscles for?" and "what would happen if someone didn't have any muscles ?" were ordered with respect to the following coding scheme (See Appendix H for examples of children's responses at each level.):

Level 4: Movement

Level 3: Strength; speed

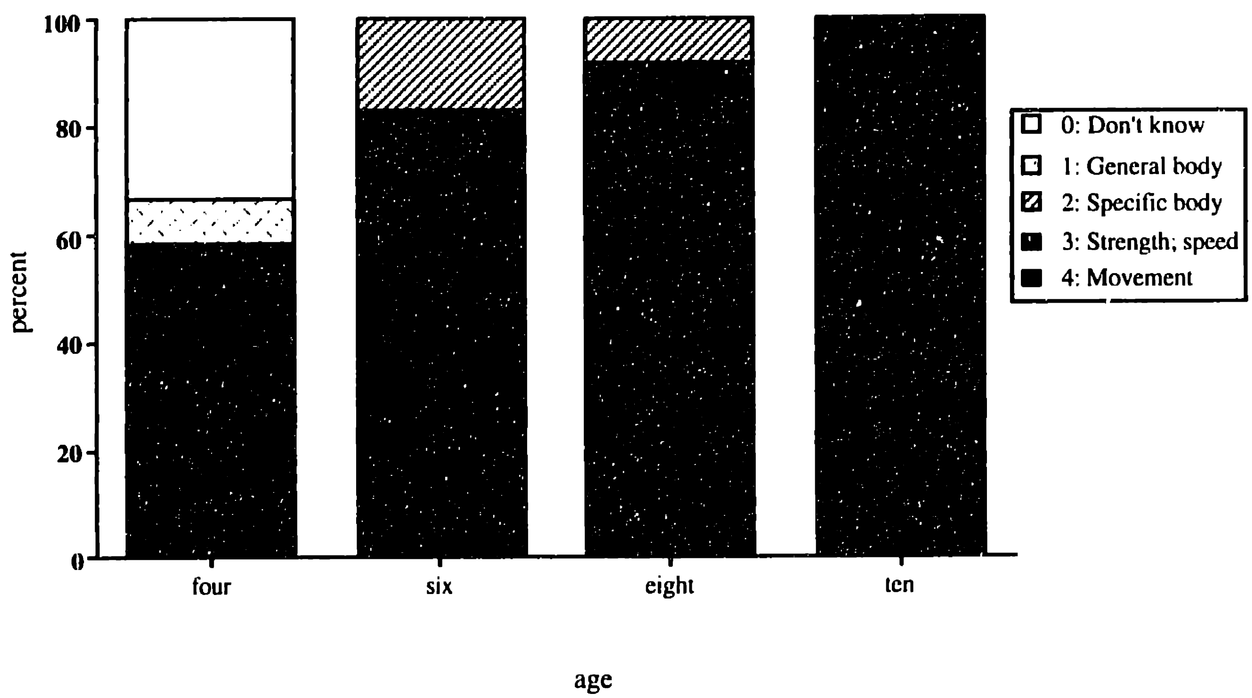
Level 2: Specific body function (e.g., to swallow; breathing; transport food/air)

Level 1: General body function (e.g., for the body)

Level 0: Don't know

Figure 2.10 shows the percentage of children at each age giving each level of explanation. As before, the bars on the graph are arranged to proceed from lightest for the lowest-level explanation to darkest for the highest-level explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data revealed a significant difference between ages on the level of explanation given, $H(3) = 12.29$, $p < .01$. Follow-up Mann-Whitney U tests (corrected for ties) revealed a significant difference between 4- and 6-year-olds, $Z = -2.18$, $p < .03$, but no significant differences between 6- and 8-year-olds ($p > .59$), nor between 8- and 10-year-olds ($p > .47$).

Figure 2.10. MUSCLES -- percent of children at each level of explanation



As shown in Figure 2.10, half of the 4-year-old children said that muscles were for strength, and a third simply didn't know what muscles were for. Only one 4-year-old said that muscles were for moving. In contrast, at ages 6 - 10, from 42 - 62% of the children said that muscles were for moving, although strength also continued to be a popular response at all ages.

2.7.3. Summary for Musculo-Skeletal System

With respect to children's knowledge of the musculo-skeletal system, we again find a shift in children's explanations for body part function between 4 and 6 years of age. In children's explanations of both muscle and bone function, we found a significant difference in explanation level between 4- and 6-year olds, but not between 6- and 8-year-olds, nor between 8- and 10-year-olds. With respect to body part locations, in contrast, there was no analogous 4-to-6 shift. Rather, the leap in knowledge of locations seems to occur between 6 and 8 years of age, during which time children go from localizing the bones and muscles exclusively in the limbs, to realizing that bones and muscles are located throughout the entire body.

2.8. Functional explanation shift for internal organ function

Generally speaking, children's explanations about the functions of internal body parts appear to undergo a significant shift between 4 and 6 years of age. Table 2.12 shows the ages at which there was a significant shift in children's level of functional explanation for each of the internal body parts. As shown in the table, there was a significant shift between the ages of 4 and 6 for seven of the eight internal body parts. In contrast, significant shifts between the ages of 6 and 8, and between 8 and 10, were found for only one out of the eight internal body parts each.

Table 2.12. Age of significant shifts in children's functional explanations of internal body parts

Body part	4 --> 6	6 --> 8	8 --> 10
heart	X	--	--
blood	X	--	--
lungs	X	--	--
stomach	X	--	--
brain	X	X	--
nerves	--	--	X
bones	X	--	--
muscles	X	--	--

The question which immediately arises, therefore, is how best to characterize and explain this pervasive shift. One possibility is that, between the ages of 4 and 6, children are simply learning a large amount of factual knowledge about the body. A second possibility is that this shift is of a more specific nature, such that it differentially affects children's functional explanations.

Based on the data presented so far, there are two reasons to doubt the "increase in general knowledge" story as the entire explanation for this 4-to-6 shift. First, although it is certainly the case that between the ages of 4 and 6, children learn some factual information about the body, for many body parts it was simply not the case that the difference between 4- and 6-year-olds was that 6-year-olds knew the correct canonical function. For example, at age 6, only approximately 40% of the children knew that the heart pumps blood, 25% knew that blood transports materials throughout the body, and less than 10% knew that lungs are responsible for taking in air. Rather, the increase seems to be better characterized as pertaining to the <u>level</u> of explanation for bodily function (i.e., from more general to more specific explanations), even if the more specific explanations are incorrect.

Second, if the 4-to-6 shift is due to a sudden spurt in general knowledge, then we would expect to see this spurt reflected globally across all measures of bodily knowledge. However, this is not the case. For example, Table 2.13 shows the ages at which there was a significant shift in children's correct locations for each of the internal body parts.

Table 2.13. Age of significant shifts in children's correct locations for internal body parts.

Body part	4 --> 6	6 --> 8	8 --> 10
heart	--	--	--
blood	?	--	--
lungs	X	--	--
stomach	--	--	--
brain	X	--	--
nerves	--	--	--
bones	--	X	--
muscles	--	X	--

As shown in the table, there were significant shifts between the ages of 4 and 6 for only two (or three)[13] of the eight internal body parts. There was a similar shift between the ages of 6 and 8 for another two of the eight internal body parts. Finally, there were no significant shifts between any two consecutive ages for three of the internal body parts. Thus, the pervasive 4-to-6 shift that we clearly see in levels of functional explanation does not seem to be represented in the case of body part location.

Due to these two factors -- (1) 6-year-olds' lack of knowledge of correct functions, and (2) failure to see a similar knowledge shift with respect to organ locations -- it seems plausible to argue that the shift we see between the ages of 4 and 6 in children's functional explanations is something which is specific to functional explanations young children give for body parts. However, there are at least two possible explanations for this shift. One reason might be that children undergo some type of significant change in how they reason about the workings of the body between the ages of 4 and 6, and this change is reflected in the specificity of their explanations. An alternative explanation is that 4-year-olds are simply incapable of providing specific functional explanations, even if they have the same knowledge as older children. If this were the case, then we would

[13] As mentioned previsously, it is unclear whether the shift in blood location is due to a shift in knowledge or is the result of a coding difficulty.

expect 4-year-olds to give the same type of vague functional explanations even in situations where they have the same specific functional knowledge as older children. To explore this issue, we next examine children's knowledge of external body parts, in which we find a different pattern of explanation than that which we have observed so far.

2.9. External Body Parts

2.9.1. Eyes.

Location. The location of the eyes in the children's drawings were coded into 2 general locations: (a) *head; and (b) other. At all ages, every child located the eyes inside the head. Although at the youngest age, several children drew the eyes in the incorrect location in the head, this seemed to be due to drawing ability, rather than to any lack of knowledge as to where the eyes were (i.e., they could all point to where the eyes were).

Function. Children's answers to the questions "what are the eyes for?" and "what would happen if someone didn't have any eyes?" were ordered with respect to the following coding scheme (See Appendix I for examples of children's responses at each level.):

Level 3: Looking; seeing

Level 2: Specific body function

Level 1: General body function (e.g., for life, health, the body)

Level 0: Don't know

At all ages, every child expressed the highest level explanation (Level 3) that the eyes are for seeing or looking.

2.9.2. Hands

Location. At all ages, every child correctly located the hands on the body outline, either by pointing or circling the hands.

Function. Children's answers to the questions "what are hands for?" and "what would happen if someone didn't have any hands?" were ordered with respect to the following coding scheme (See Appendix J for examples of children's responses at each level.):

Level 3: Feeling, touching, acting on objects

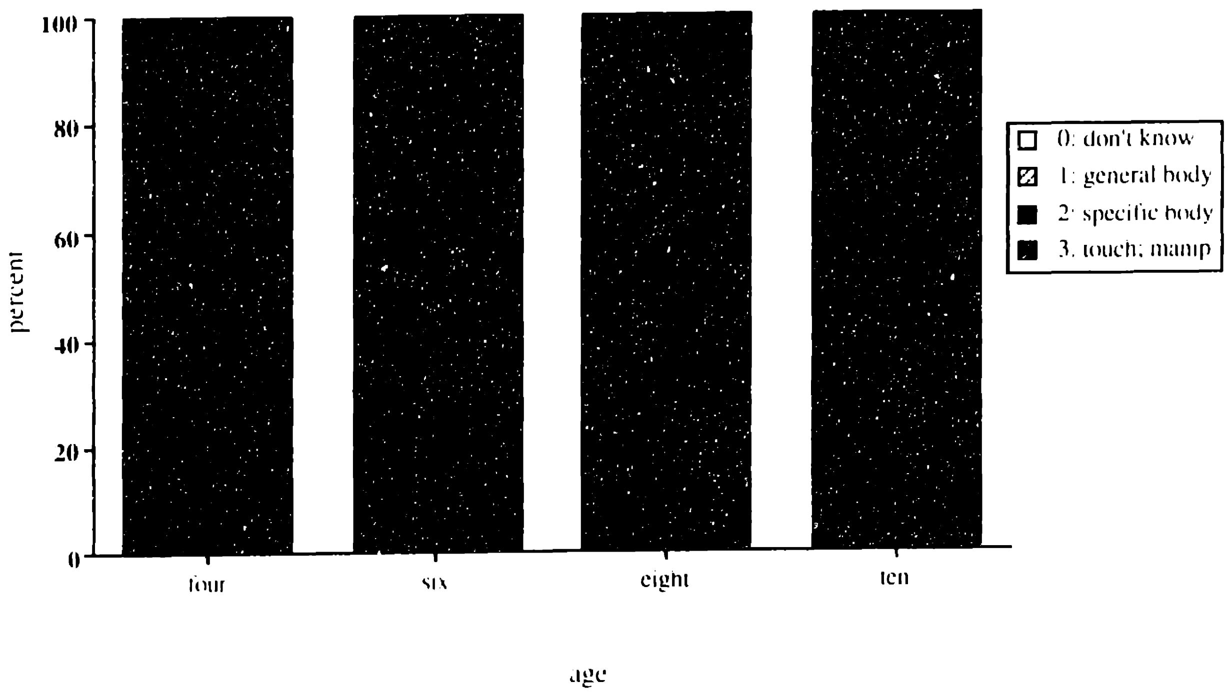
Level 2: Specific body function (e.g., moving)

Level 1: General body function (e.g., for life, health, the body)

Level 0: Don't know

Figure 2.11 shows the percentage of children at each age giving each level of explanation. As with the internal body parts, the bars on the graph are arranged to proceed from lightest for the lowest-level explanation to darkest for the highest-level explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data revealed no significant difference between ages in the level of explanation given ($p > .37$). In fact, as shown in the figure, all children except for one 4-year-old expressed the highest level explanation that hands are for touching and/or manipulating objects.

Figure 2.11. HANDS -- percent of children at each level of explanation



2.9.3. Skin

Location. The location of the skin was coded from both the children's drawings and verbal responses (e.g., "It's all over") into two categories: (a) localized on a particular bodily area; and (b) everywhere. Table 2.14 shows the percentage of children at each age locating the skin in each of these locations. A chi-square analysis on these data showed a significant difference between ages in the number of children locating the skin in these different locations, χ^2 (3) = 30.22, $p < .001$. Specifically, there was a significant difference between the 4- and 6-year-olds, χ^2 (1) = 10.67, $p <$ .01, but no significant differences between the 6- and 8-year-olds ($p > .15$), nor between the 8- and 10-year-olds. This pattern can presumably be explained by the fact that 83% of the 4-year-olds localized the skin in a particular location, while only 17% said skin was everywhere. In contrast, 83% of the 6-year-olds said the skin was everywhere, while only 17% said the skin was localized in a particular area.

Table 2.14. Percent of children at each age locating the skin in each area.

	Four	Six	Eight	Ten
localized	83	17	0	0
*everywhere	17	83	100	100

In light of the above analysis, however, it is important to point out the very likely possibility that the "localized" category was largely due to ambiguity of response. Virtually all children coded with this response simply pointed to a patch on their own skin, and then indicated that they were unable to draw it on the picture.

Function. Children's answers to the questions "what is skin for?" and "what would happen if someone didn't have any skin?" were ordered with respect to the following coding scheme (See Appendix K for examples of children's responses at each level.):

Level 4: Protection; warmth

Level 3: Organ/blood container; holds together

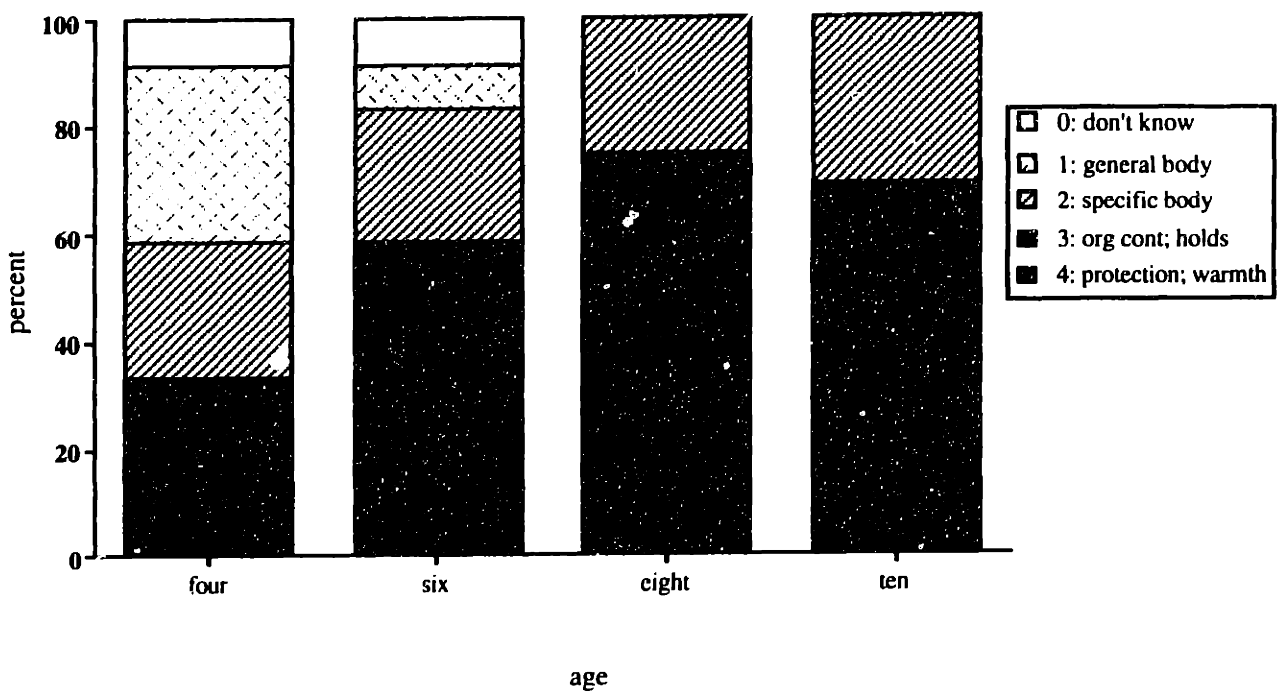
Level 2: Specific body function (e.g., gives substance; opaqueness)

Level 1: General body function (e.g., for life, health, the body)

Level 0: Don't know

Figure 2.12 shows the percentage of children at each age giving each level of explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data showed a significant difference between ages on the level of explanation given, $H(3) = 10.88, p < .02$. However, follow-up Mann-Whitney U analyses (corrected for ties) revealed no significant differences between any two successive age groups. At all ages, children said that skin was for: (a) "covering" your body so that your insides wouldn't show (this was the almost exclusive answer for Level 2); and (b) for "holding things in" and/or holding you together (Level 3). In addition, there seems to be an increase with age for explaining the skin's function in terms of protection or warmth (Level 4).

Figure 2.12. SKIN -- percent of children at each level of explanation



Comparisons between these data and the results from previous studies are difficult, largely due to differences in coding and age grouping. Gellert (1962) categorized children's explanations of skin function into 12 categories, with each child's response falling into one or more categories. Because these categories were neither mutually exclusive nor hierarchically organized, it is difficult to compare the whole of her data with ours. However, several of her categories map rather straightforwardly onto our own: (1a) *Skin covers insides*, and (b) *Function explicitly related to appearance* [Our Level 2]; (2) *Function related to keeping and/or holding body together* [our Level 3]; and (3) *Function related to protection* [our Level 4]. As in the current study, Gellert found that children of all ages explained skin function in terms of covering the insides and holding the body together. In addition, she also found a dramatic increase in the number of children explaining skin function in terms of protection between ages 4-8 (5%) and 9-12 (58%). This increase in the current study is not so dramatic, presumably due to the greater rate of this explanation among our 4- to 8-year-olds (as well as the fact that we did not test 12-year-olds).

2.9.4. Teeth

Location. The location of the teeth in the children's drawings were coded into 2 general locations: (a) *head; and (b) other. At all ages, every child located the teeth inside the head. Although at the youngest age, several children drew the teeth in the incorrect location in the head, this seemed to be due to drawing ability, rather than to any lack of knowledge as to where the teeth were (i.e., they could all point to where the teeth were).

Function. Children's answers to the questions "what are teeth for?" and "what would happen if someone didn't have any teeth?" were ordered with respect to the following coding scheme (See Appendix L for examples of children's responses at each level.):

Level 3: chewing; eating; biting

Level 2: Specific body function (e.g., talking, protection)

Level 1: General body function (e.g., for life, health, the body)

Level 0: Don't know

At all ages, every child expressed the highest level explanation that the teeth are for chewing or biting.

2.9.5. Tongue

Location. The location of the tongue in the children's drawings were coded into 2 general locations: (a) *head/throat; and (b) other. At all ages, every child located the tongue inside the head or throat. Although at the youngest age, several children drew the tongue in the incorrect location in the head, this seemed to be due to drawing ability, rather than to any lack of knowledge as to where the tongue were (i.e., they could all point to where their tongue was).

Function. Children's answers to the questions "what is the tongue for?" and "what would happen if someone didn't have a tongue?" were ordered with respect to the following coding scheme (See Appendix M for examples of children's responses at each level.):

Level 3: tasting; talking; eating components (e.g., licking, chewing)

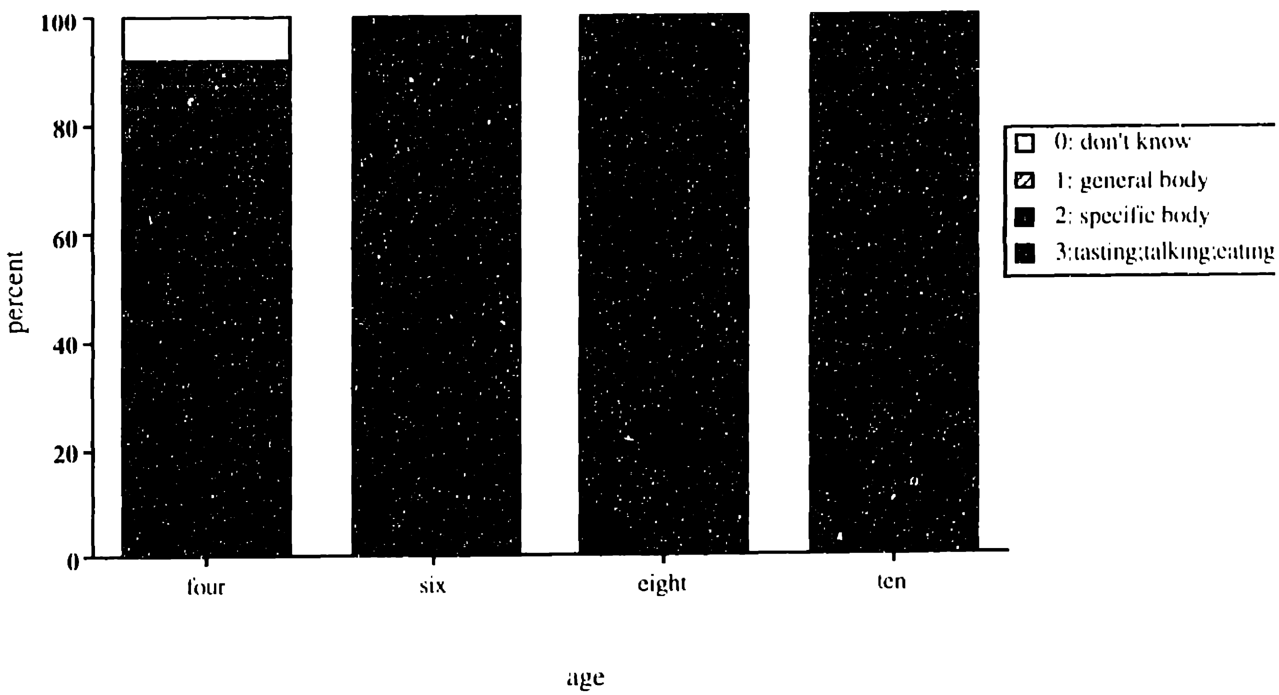
Level 2: Specific body function (e.g., sneezing; moving)

Level 1: General body function (e.g., for life, health, the body)

Level 0: Don't know

Figure 2.13 shows the percentage of children at each age giving each level of explanation. A one-way Kruskall-Wallis analysis of variance (corrected for ties) on these data showed a significant difference between ages on the level of explanation given, $H(3) = 9.64$, $p < .03$. However, follow-up Mann-Whitney U analyses (corrected for ties) revealed no significant differences between any two successive age groups. At all ages, at least 75% of the children explained tongue function in terms of tasting, talking, and various components of eating.

Figure 2.13. TONGUE -- percent of children at each level of explanation



2.9.6. Summary of External Body Parts

Children's explanations for external body parts generally did not follow the same 4-to-6 shift that characterized the explanations for internal body parts. Rather, children at all ages tended to offer the same types of explanations (and indeed, often the same explanation) for external body parts. For example, at all ages, children said that the eyes were for seeing and that teeth were for chewing. This suggests that the differences found between 4- and 6-year-olds with respect to their explanations for internal body parts cannot be explained by positing that 4-year-olds are simply incapable of providing specific functional explanations for body parts.

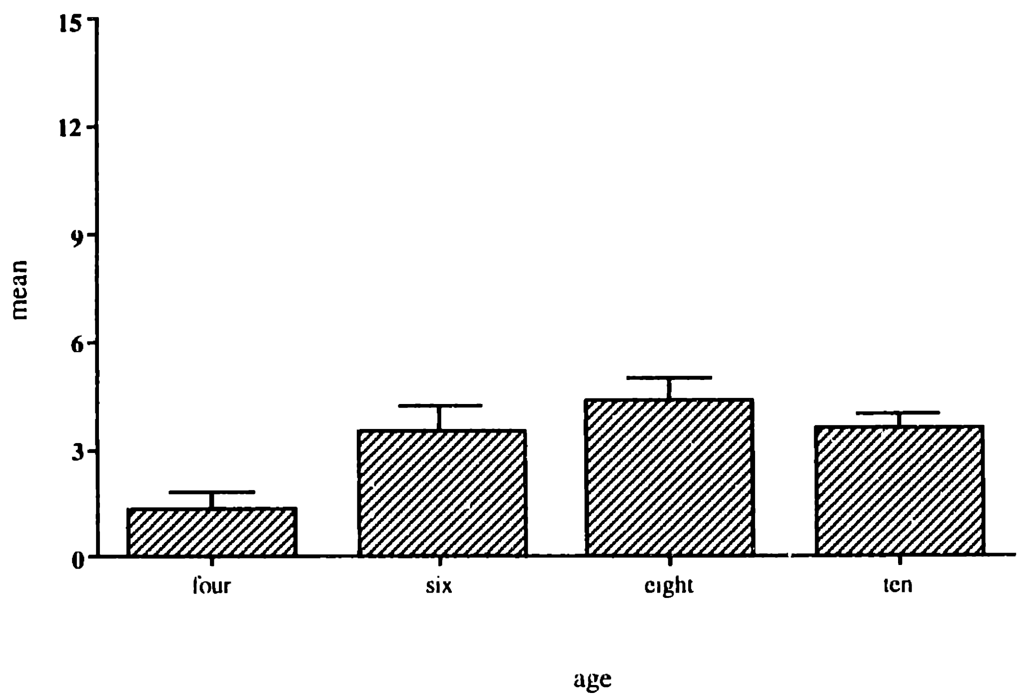
2.10. "Life" as a Biological Goal

One major goal of this study was to examine the type of functional explanations that children use in reasoning about the body. We approached this in two ways. First, we looked at the level of specificity and correctness children used in explaining bodily functions. This was embodied in the coding levels constructed for each body part. In addition, because we were especially interested in children's knowledge of specifically biological goals, we also examined children's explicit appeal to perhaps the most fundamental biological goal -- that of maintaining life.

2.10.1. Appeals to Life

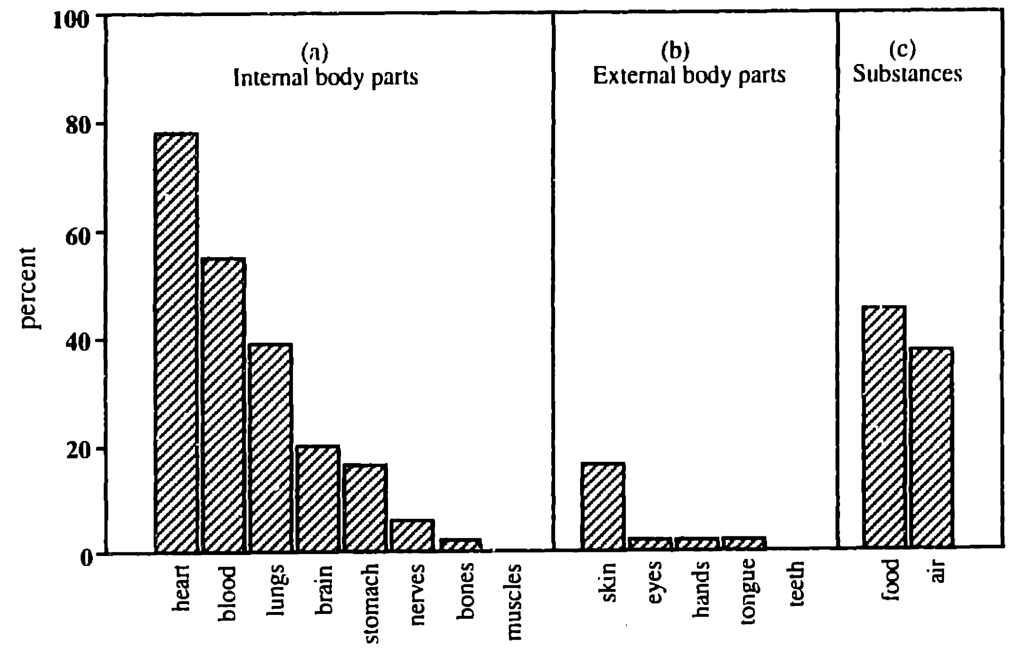
Children were given a score of 1 for each body part for which they mentioned the goal of maintaining life (or avoiding death); they were given an additional point if they appealed to life for the question of why we eat food, and also for why we breathe air -- resulting in a total possible score of 15. Figure 2.14 shows the mean number of appeals to the goal of maintaining life at each age.

Figure 2.14. Mean number of appeals to "Life" at different ages



Perhaps the first thing one notices from the figure is that at all ages, children made relatively few direct appeals to the goal of maintaining life. That is, although children did mention life and death in their explanations of body part function, at no age did they ubiquitously appeal to life as the ultimate goal for all body parts. Within this low overall response rate, there were also large asymmetries in which body parts children deemed necessary for life (See Figure 2.15).

Figure 2.15. Percent of children appealing to "Life" for different body parts and substances



As shown in Figure 2.15, the heart was seen by the most children as necessary for life, followed by blood and the lungs. Food and air were also seen as life-necessary for a large proportion of the children (approximately 40%). None of the 10 other body parts tested were described as being necessary for life by more than 20% of the children. Of course, this asymmetry should be expected to some degree, due to the fact that some body parts (e.g., hands, teeth) are clearly not necessary for maintaining life. Even within the "vital" body parts, however, we still see large asymmetries. Notice, for example, that while the heart was viewed as life-necessary by approximately 80% of the children, the brain was viewed as life-necessary by only 20% of the children.

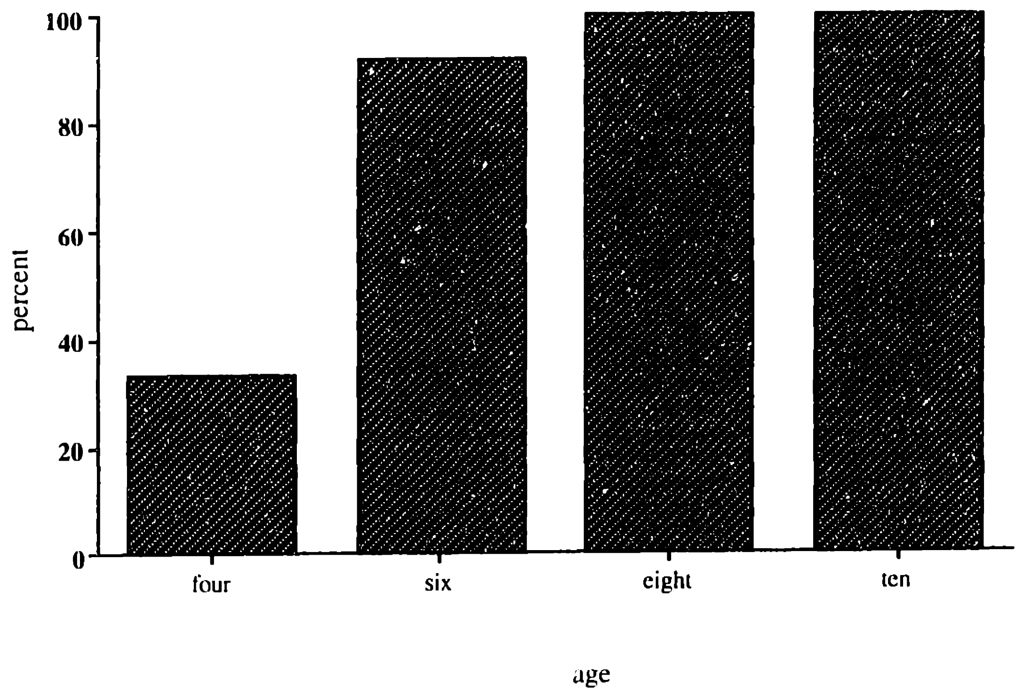
In addition to the asymmetry between body parts, there was also a significant difference between ages in the number of overall appeals to Life, $F(3, 45) = 5.42, p < .005$ (See Figure 2.14). Specifically, 4-year-olds made significantly fewer appeals to Life than did 6-, 8-, and 10-year-olds (Fisher, p's $< .05$). There were no significant differences among the other age groups. Thus, with respect to children's explicit appeal to the most fundamental biological goal -- Life -- we again see an apparent discontinuity at the same 4-to-6 boundary at which we saw the functional explanation shift with respect to the functions of internal body parts.

2.10.2. Life - Theory

Because of our interest in whether biological teleology functions as a causal principle in young children's emerging biological reasoning, we also examined children's individual patterns of appealing to life. For these purposes, we characterized children as "Life-Theorizers" if they mentioned the goal of maintaining life (avoiding death) for more than one organ or substance (including the questions of eating food and breathing air). Our rationale for this was simple. Clearly, to argue that children are using Life as an ultimate biological goal, children must actively use this Life concept in their reasoning about body part functions. However, we certainly don't want to require that they use this concept to explain all, or even most, body part functions. Even adults wouldn't claim that all body parts are necessary for life. Moreover, we want to capture the beginning or emergence of this idea in children's reasoning -- which very likely may begin with only a few "vital" body parts (e.g., heart and blood). Operationally speaking, then, we simply required that Life-Theorizers appeal to Life "more than once".

The number of Life-Theorizers at each age is presented in Figure 2.16. There was a significant difference between ages in the number of Life-Theorizers, $\chi^2(3) = 25.10, p < .001$. Specifically, there was a significant difference between the 4- and 6-year-olds, $\chi^2(1) = 8.71, p < .01$, but not between the 6- and 8-year-olds, nor between the 8- and 10-year-olds.

Figure 2.16. Percent of children classified as "Life-Theorizers"



As shown in Figure 2.16, only one-third of 4-year-old children qualified as Life-Theorizers (i.e., mentioned life or death for more than one body part or substance). In contrast, by age 6, nearly all children exemplified this designation. So at the level of individual children, we again see a striking discontinuity at the 4-to-6 age boundary with respect to this idea of "Life" -- perhaps marking the beginning of biological teleology as a causal principle.

Although this increase in appeals to Life is interesting and suggestive as a descriptive phenomenon, the more relevant issue for our purposes is whether this designation does any explanatory work for us in understanding the structure or emergence of children's early biological reasoning. In other words, if Life truly acts as some sort of unifying explanatory principle in children's bodily reasoning, then ideally we would like to show that children who have this Life-Theory somehow behave differently than children who do not use life as an explanatory principle. Specifically, we would like to suggest that it is children's Life realization -- the idea that there exists a thing called Life -- which drives children to look for and think about specific explanations for body parts. If this is true, then we would expect that children who had made this realization ("Life-Theorizers" [LTs]) would score higher on explanations for (internal) body part function than children who have not made this realization ("Non Life-Theorizers" [NLTs]).

To investigate this issue, we performed a preliminary analysis on 4-year-olds -- the only age group in which there was real variation in children with respect to this purported "Life-Theory". Given the small number of 4-year-old children who were classified as LTs, this analysis was undertaken for exploratory purposes only, and should only be viewed as preliminary and suggestive. We examined the number of "high-level responses" children gave for internal body parts on two different types of questions -- function and location. For function, we defined high-level as any explanation scored at Level 2 or higher. Recall that explanations at this level involved providing some specific body function, even if that function was incorrect. Thus this measure looks directly at the specificity of children's functional explanations -- which we believe may be affected by a Life-realization. For location, we defined high-level as providing the correct location. Thus, this measure simply looks at a learned fact -- which we have no reason to believe would be affected by a Life-realization.

If the difference between LTs and NLTs is simply that LTs have learned one particular idea (e.g., people die without some body parts), but this idea plays no further role in children's understanding and reasoning about the body, then we would expect to find no differences between LTs and NLTs on either measure. If, on the other hand, the difference between LTs and NLTs is simply due to overall knowledge level about the body, then we would expect LTs to score higher than NLTs on all measures of bodily knowledge (in this case, on both function and location). Finally, if the difference between LTs and NLTs is that LTs have constructed a "Life-Theory" that plays a specific causal role with respect to children's functional explanations, then we would expect LTs to score higher than NLTs in terms of body part function, but not location.

Figure 2.17. Comparison of 4-year-old LTs vs. NLTs on High-Level Responses for Internal Body Parts

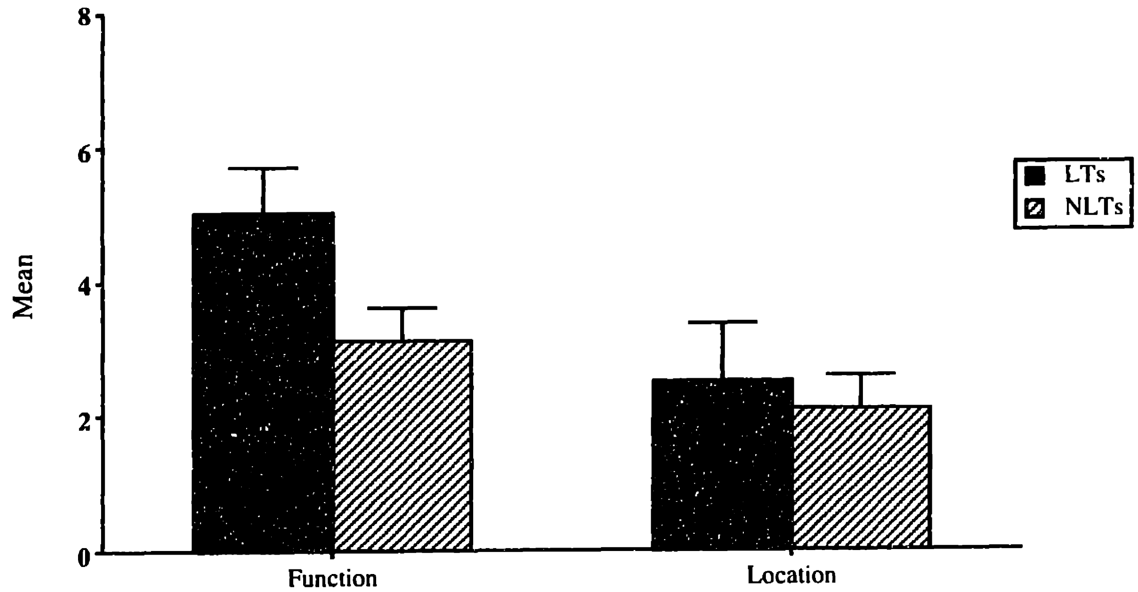


Figure 2.17 shows the mean number of high-level responses of 4-year-olds for both function and location of internal body parts (possible score = 0 - 8). A 2 (theory designation: LT vs. NLT) x 2 (question type: function vs. location) mixed Analysis of Variance was performed on these data, with theory designation as the between-subjects factor and question-type as the within-subjects factor. There was a main effect of question type, $F\,(1,10) = 18.00, p < .01$. Overall, the 4-year-old children gave more high-level responses for functional explanations than for locations of internal body parts. In addition, there was a marginally significant interaction between theory designation and question type, $F(1,10) = 4.88, p < .08$. Specifically, LTs gave significantly more specific functional explanations than NLTs, 2-tailed $t\,(10) = -2.23, p = .05$. There were no significant differences between LTs and NLTs in providing the correct location ($p > .68$).

2.10.3. Summary -- The Secret of "Life"

When we examine children's direct appeals to the goal of maintaining life, we again find a discontinuity between the ages of 4 and 6. At the group level, there was a significant increase in the number of appeals children made to life between the ages of 4 and 6. At the individual level, while only one-third of 4-year-olds qualified as Life-Theorizers, virtually all 6-, 8-, and 10-year-olds did so. In addition, we found preliminary evidence that this "Life-realization" may be the driving force behind the increase in specificity that we see in children's explanations of internal body part function.

2.11. Summary & Conclusions

The results of the current study are in general agreement with previous findings regarding children's overall knowledge of the body (e.g., Gellert, 1962; Nagy, 1953). For certain specific pieces of information (e.g., the heart pumps blood; lungs are located in the chest; the stomach digests food), the children in our study showed greater knowledge at younger ages than children in previous studies. This was presumably due to a cohort effect, most likely driven by the large amount of information about the body currently available in children's popular culture and media (e.g., *Sesame Street*; *The Magic School Bus*)

More importantly for our purposes, the results also indicated a pervasive shift in children's explanations of internal organ function between 4 and 6 years of age. For almost all of the internal organs, there was a significant increase in the level of children's functional explanations between these two ages. This shift has not been reported in previous literature, presumably because previous results did not delineate children's responses according to age (e.g., Nagy, 1953), or because the age grouping of previous studies made it impossible to observe such a shift (e.g., Gellert's [1962] study, in which 4- to 6-year-olds were considered a single age group). Although levels of explanation for internal body parts continued to increase with age, these increases were usually of a more gradual nature, rather than the sudden across-the-board shift which seemed to mark the earlier increase.

In characterizing this shift, it seems clear that it is not simply marking a global increase in knowledge about the body between the ages of 4 and 6. First, this difference is not simply due to children learning the "correct information" about organ function between the ages of 4 and 6. In fact, relatively few children at age 6 actually knew the correct function for many of the body parts. Second, this increase seems to be specific to knowledge of organ function, as shown by the fact that there was not a similar sudden increase in knowledge of organ locations between these two ages. Rather, the shift seems to be better characterized as pertaining to the level of explanation for bodily function, moving from more general to more specific explanations. In addition, this shift was not due to 4-year-olds' inability to give specific functional explanations, as shown by the fact that they gave specific explanations for external body parts. Taken together, these results suggest that children undergo some type of significant change in how they reason about the internal workings of the body between the ages of 4 and 6, and this change is reflected in the specificity of their explanations.

In addition to the explanation shift for internal organ function, there was also a dramatic increase in children's appeals to the goal of maintaining Life between the ages of 4 and 6. While less than half of the 4-year-olds mentioned this goal in connection with more than one organ or substance, virtually all of the 6-, 8-, and 10-year-olds did so. Moreover, preliminary analyses indicated that the tendency of children to appeal to Life was associated with greater specificity in their explanations of organ function. This suggests that the pervasive explanation shift we are seeing is a reflection of children's discovery that there exists a thing called "Life" and that body organs function to support life. If this is true, then this would certainly qualify as biological teleological reasoning, and would thus indicate the beginning of a biological theory.

Corroborating evidence for the importance of this Life-realization in children's bodily reasoning has recently been provided by Slaughter's (1997) study of young children's knowledge of life and death. In this study, she interviewed 4- and 5-year-old children about body organ functions and death. On the basis of their responses to the body questions, Slaughter classified the children as either Life-Theorizers or non-Life-Theorizers (using the criteria of the current study).

She then examined their responses to the questions about death on the basis of this classification. Overall, she found significant differences between the two groups, in that Life-Theorizers gave more sophisticated, adult-like answers to various questions about death (e.g., "Does every person die? What happens to the body when people die? When a person is dead, do they need food?"). These results support the idea that those children we have called "Life-Theorizers" are indeed beginning to construct a coherent theory encompassing bodily organ function, life, and death.

With respect to the predictions made in the beginning of this chapter, then, we seem to be in disagreement with everyone. First, contrary to Keil's (1992, 1994) views, we did find a dramatic change across ages in how children reason about bodily organs. This change did not seem to be explainable on the basis of the gradual accumulation of factual knowledge, but rather by the addition of a new causal principle between 4 and 6 years of age. Second, this reorganization comes at a much younger age than would be predicted by Carey (1985b) and by Inagaki and Hatano (1993). However, it should be noted that the shift we have documented is with respect to a particular causal explanatory principle -- biological teleology. It is possible that additional shifts in children's bodily knowledge occur at later ages, perhaps with respect to other explanatory principles.

In conclusion, the results of the current study suggest a major reorganization in children's bodily knowledge between the ages of 4 and 6. We propose that this reorganization in body knowledge can be characterized as a shift from <u>no</u> biological theory to the <u>first</u> biological theory, perhaps with biological teleology (that is, teleological reasoning with respect to biological goals) as the first biologically specific causal principle.

2.12. Appendices -- Examples of children's responses.

Appendix A: HEART

LEVEL 0:	DON'T KNOW; BEATING
for	beating
w/o	[don't know]
LEVEL 1:	GENERAL BODY FUNCTION
for	for my stomach
for	helping your body
for	It helps you live cuz if your heart stops beating then you die. [E: Well how come?] Well cuz... um... well, it's your heart that makes you die because your heart stops beating, and then you're dead.
for	your life
w/o	couldn't help your body.
w/o	die. [E: They'd die. Well how come?] 'Cuz they don't got a heart.
w/o	They would die. [E: They would? Well how come?] Cuz, if it -- if they have two of 'em, and ... if they had one of 'em and it just beeped, they would really die.
w/o	they'd die. [E: They'd die? Well how come?] They have no life.
LEVEL 2:	SPECIFIC BODY FUNCTION
for	thinking
for	to be able to breathe
for	It takes in the air and it makes your body go.
w/o	they couldn't breathe.
w/o	they wouldn't think

LEVEL 3:	BLOOD FUNCTION
for	blood goes into it, and it cleans the blood
for	Um... to control, like um, your blood and stuff.
for	for blood pressure and for living

LEVEL 4:	PUMP BLOOD
for	to make your blood go through your body.
for	pump the blood
for	It pumps blood all over your body.
for	To beat your blood around your body, through your (veins?).
w/o	They would die. [E: Well how come?] Cuz it wouldn't pump the blood anywhere.
w/o	They would be dead. [E: Do you know why?] Cuz your heart pumps blood and you need blood.
w/o	You'd die. [E: Well how come?] Because they didn't have blood circulating through their body, and... they need that.
w/o	They'd die. [E: They'd die. Well how come?] Cuz nothing would be able to move their blood.

Appendix B: BLOOD

LEVEL 0:	DON'T KNOW; TAUTOLOGY
for	[don't know]
for	bleeding
for	being hurt
for	for, like, getting boo-boos
for	It's to... in case like you cut yourself.
w/o	They couldn't bleed if they got hurt.

w/o	you couldn't be hurt

LEVEL 1: GENERAL BODY FUNCTION

for	it's for... your body?
for	for the stomach
for	to help you live
for	to keep you alive.
w/o	they would die
w/o	Then they wouldn't be alive.
w/o	They'd really die. [E: Well how come?] Cuz, um... cuz if they didn't have blood, they would die. They'd really die. They'd really really die. [E: They'd really really die? Well how come they'd die? Do you know?] Cuz if they die -- if they don't have blood, they really -- they die....

LEVEL 2: SPECIFIC BODY FUNCTION

for	breathing
for	So it can make your heart beat. [E: Uh-huh] And when it goes up to your brain it makes your brain think harder.
for	to help you move and stuff.
for	to keep you warm
for	So that it can... well... so that your body'll be made of fluid. [E: Uh-huh] And that - so it can... make your bones and your lungs and everything work.
w/o	maybe they would just dry up or something.
w/o	Then nothing would keep going and it would just be like a statue.
w/o	they couldn't breathe at all
w/o	they would be... not warm
w/o	they wouldn't be strong
w/o	If you don't have blood, your heart can't keep going.

LEVEL 3 — TRANSPORT AIR and/OR FOOD; ATTACK GERMS

for — Blood carries your food to your intestines.

for — When you eat your - it sort of like carries the food around to parts of your body that need it.

for — It carries food all over your body so your arms and hands can move, and your legs can move, and everything can move.

for — Your blood keeps your -- all the good blood cells -- all the red blood cells make up the blood, and the white blood cells destroy the disease germs; they're like soldiers.

Appendix C: LUNGS

LEVEL 0: — DON'T KNOW

for — [don't know]

LEVEL 1: — GENERAL BODY FUNCTION

for — they're for... keep your body

w/o — die. [E: Yeah, well how come?] Cuz they didn't have lungs.

w/o — I don't know. [E: Could you guess?] Well, I'd die I think. [E: Well how come?] Because, um, nobody would have no lungs. They would um, like - I think your lungs are connected to something that's really important to you.

LEVEL 2: — SPECIFIC BODY FUNCTION

for — moving

for — maybe like, pretty much like just... making it so that your heart doesn't... like so that your neck doesn't really like cave in.

for — to taste things and stuff

for — To stop, um, air from going into your body.

w/o — won't be able to move your muscles

w/o	You couldn't be able to swallow nothing.
w/o	All the germs would go into their body.

LEVEL 3:	BREATHING (ACTIVITY)
for	breathing
for	to help you breathe
w/o	they'd die. [E: Well how come?] They can't breathe.
w/o	they wouldn't be able to breathe

LEVEL 4:	AIR INTAKE
for	air
for	breathing. When you breathe in then your lungs fill up with air. And when you breathe out, they empty themselves out.
for	The lungs take in the air and they blow out -- they send out the air that is bad for you.
for	To breathe in, and they hold oxygen.

<u>Appendix D: STOMACH</u>

LEVEL 0:	DON'T KNOW; STOMACH-ACHE
for	I know, um... having a stomach-ache. I don't know.
for	[don't know]

LEVEL 1:	GENERAL BODY FUNCTION
w/o	they would die
w/o	I don't think they would be alive. [E: How come?] Cuz... I don't know.

LEVEL 2: SPECIFIC BODY FUNCTION

for it's where the lungs is, and the heart is

for so you can breathe

w/o Well, they wouldn't have a heart, cuz that's where the heart goes. And, um, they wouldn't have the bones there.

LEVEL 3: FOOD CONTAINER; EATING; NOURISHMENT

for for food

for So when your food goes all the way down there [points], well, it goes down down down and the food doesn't go down to your feet. Do they? They go into your belly.

for Your food goes down into your stomach.

for to hold the things that you eat

for catching the food

w/o they can't eat

w/o The food would keep going and the drink would keep going all the way down to the bottom of your feet. [E: Well then what would happen?] Then you wouldn't be able to walk because you would have bumps in your feet.

w/o the food would just pour out onto the floor.

w/o the food would just go right down to their feet. [E: Whoa. And then what do you think would happen?] I don't know -- it'd stay there.

w/o The food would just wander around their body.

w/o Food would be floating all over their body.

LEVEL 4: DIGESTION

for your food goes into your stomach. It digests it.

for It holds your food. And it cuts down the food so it can be carried off with the blood.

for churns up everything and it sends the good things out to the different parts. [E: You said it churns up everything. What do you mean by "everything"?] It churns up the food you eat into a thick liquid.

for To mush food.

w/o They wouldn't be able to digest their food.

w/o No food would get digested... and if they kept on eating, their stomach would get big and it'll probably, like, stick through.

Appendix E: BRAIN

LEVEL 0: DON'T KNOW; HEADACHE

for [don't know]

for when you get a headache, maybe it turns red.

w/o Probably they would be weird. [E: They would be weird. Well how come?] Because they wouldn't have a brain.

LEVEL 1: GENERAL BODY FUNCTION

for It's for keeping your body good.

for it's for your stomach

w/o maybe they would die too. [E: Well how come?] Cuz, if they don't have a brain, they'd really die.

w/o They wouldn't be alive.

w/o They couldn't do much, and they wouldn't live very long either.

LEVEL 2: SPECIFIC BODY FUNCTION

for to make the heart work

LEVEL 3: THINKING; COGNITIVE FUNCTION

for thinking

for for you to think and to do things right and to be smart.

for — for thinking, and figuring out things. Basically,... well like to be smart and stuff. If you have brain damage, you aren't that smart, and I don't wanna be that way.

for — to help you learn or... help you read or something

for — So you can think of different things when the teacher asks you. [E: Uh-huh] So you can remember notes.

w/o — couldn't think

w/o — They wouldn't be smart.

w/o — well, for one thing, they'd be stupid. And they couldn't think straight.

w/o — Well, they'd - I don't know if they'd die or not, but... they probably would. Or, they wouldn't be able to think very well, and they wouldn't be able to do anything.

LEVEL 4: SPECIFIC CONTROL

for — To make your body move, cuz when the heart pumps to your brain, your brain can like um send - send messages to a part of the body, then the, um, heart pumps blood to that part so you can move. And it goes real fast.

for — To think and it tells every part -- like if I wanna move this hand, the brain will send a message down to the hand that I wanna move.

for — It sends little, um, whatever... sort of like electricity, but it makes your hands move -- it tells your hands, "move". And... it helps you think; memory; one plus one equals two and other stuff; your abc's.

for — It's to, um, control your muscles, and, mostly every part of your body.

for — To make your body move. Like, the left side controls the right side, and the right side controls the left side.

Appendix F: NERVES

LEVEL 0: DON'T KNOW

for — [don't know]

LEVEL 1:	GENERAL BODY FUNCTION
for	body
w/o	I think they'll die. [E: You do? Well how come?] [don't know]
w/o	they would die?
LEVEL 2:	SPECIFIC BODY FUNCTION
for	The nerves take the food from the stomach and they send it out.
for	They're for doing things like this. [waves hands and arms] [E: Doing things like that -- Like waving your arms?] Yeah.
for	Um, so that it can protect the layer of your skin [E: Uh-huh], so that if anything comes near your skin, it won't infect or hurt it.
w/o	I would guess it would be very hard to get blood all over your body
w/o	If they had a cut, the nerves wouldn't be there to let it not come in and it could infect your body.
LEVEL 3:	THINKING; EMOTIONS
for	nerves are for in case you get scared
for	In case you get nervous.
w/o	they couldn't think
w/o	they'd be scared all the time, maybe
w/o	then they wouldn't be able to get scared
w/o	They would never get nervous.
LEVEL 4:	SEND MESSAGES; SENSATION
for	feeling; so you can feel.
for	If you cut yourself the nerve tells you that you can feel things and like if you cut yourself it would hurt, so you can feel hurt.
for	uh, let's see... Nerves help you move. [E: Uh-huh] Let's see, the nerves... The nerves make - uh, send messages up to your brain... from your spine.

w/o	[pretends to hit self] - wouldn't feel it. Punch - wouldn't feel it. Then nothing would happen to them. If they were closing their eyes and they fell over or something... or anything like that - if they were like blind, couldn't walk, and they um like fell into the street and they got ran over, they wouldn't feel anything.
w/o	They couldn't feel anything.
w/o	You wouldn't be able to feel things.... Well, like if you didn't have nerves and you put your hand on a hot stove, you wouldn't know you would be burning yourself.

Appendix G: BONES

LEVEL 0:	DON'T KNOW
for	[don't know]
for	Bones are for... um, they're for nothing.
LEVEL 1:	GENERAL BODY FUNCTION
for	they're for... your body
for	bodies
w/o	they couldn't have any any any heart
w/o	They'd die.
LEVEL 2:	SPECIFIC BODY FUNCTION
for	being strong
w/o	they would be all... they would be all... they would not be that strong
w/o	If no one had bones, um... um, then it... [mumble]... then the food can't go down through the bones.
LEVEL 3:	MOVEMENT

for	to move
for	to help you move
for	like you can move your things and stuff around
for	To bend your body.
w/o	they couldn't move at all
w/o	they can't move. They'd have to go in a wheelchair.
w/o	they wouldn't be able to walk that good

LEVEL 4:	STRUCTURE and SHAPE; PROTECTS ORGANS
for	They're for having -- um, to make you hard so nobody can squish you.
for	to help you stand up
for	so you won't be wobbly
for	Bones help keep stiff, cuz I couldn't turn my bone all the way around cuz my joint doesn't do that.
for	They keep you up and they keep your body straight.
for	Well, maybe for to keep all your skin together, all of your body parts together.
for	So you can move your different muscles. [E: Uh-huh] And, like your rib cage, it usually protects your lungs and your heart.
for	To protect body parts and so you won't be like rubber, fall or something.
w/o	If we didn't have bones, then we'd like squeeze ourselves, and we'd be soft like a sponge.
w/o	We'd be all flat like paper or something.

Appendix H: MUSCLES

LEVEL 0:	DON'T KNOW
for	[don't know]

LEVEL 1: GENERAL BODY FUNCTION

for bodies

LEVEL 2: SPECIFIC BODY FUNCTION

for They're for when you breathe in and out. When you breathe in and out, like, they sort of help you - I don't really know.

for Your muscles take in the air and send it to all the different parts of your body. Sometimes I just forget what they're for.

LEVEL 3: STRENGTH; SPEED

for they are for getting you stronger

for to be strong

for they make you run faster

for to be strong, and to pump the blood stream. And to, like if you were in a fight, you would have to have muscles to be strong.

for They help you be strong. [E: They help you be strong.] You can carry heavy things with 'em. [E: Uh-huh] And if, like, someone needs help getting, like, down a big box, that - that person whoever's strong can help you get it down.

w/o they couldn't be strong

w/o You wouldn't get strong. You wouldn't be able to pick any heavy things up, just light things.

w/o You'd be about the weakest person in the world.

LEVEL 4: MOVEMENT

for moving

for To help you like move, so - if I didn't have muscle I couldn't move at all, so if I have muscles I can do this and that and this... [making movements]

for They're for moving your body. [E: Uh-huh] And doing things as simple as smiling or using your eyelashes.

for — They're to help, like - if the brain wants you to move your arm, they're to help you move your arm. Or if you want to turn your head, they help you turn your head.

w/o — they couldn't move.

Appendix I: EYES

LEVEL 0: DON'T KNOW

for — [don't know]

LEVEL 1: GENERAL BODY FUNCTION

[N/A]

LEVEL 2: SPECIFIC BODY FUNCTION

[N/A]

LEVEL 3: LOOKING; SEEING

for — looking

for — seeing

for — to see

for — They let you see things, and I forget what the other thing was.

for — They're for, so you can see, and... so you can see for long distance, short distance, and usually people are sometimes near-sighted or far-sighted, so then they would might need glasses.

w/o — you wouldn't be able to see. You would just crash when you're driving.

w/o — they wouldn't be able to see; they would be blind

w/o — They'd be blind.

Appendix J: HANDS

LEVEL 0:	DON'T KNOW
w/o	You couldn't really do much.
LEVEL 1:	GENERAL BODY FUNCTION
w/o	They would die. [E: Well how come?] Because the hands are a part of your skin, and um, and if you didn't have no hands you couldn't do anything.
LEVEL 2:	SPECIFIC BODY FUNCTION
for	They're for doing like open them up and open them shut. [demonstrates]
LEVEL 3:	FEELING; TOUCHING; ACTING ON OBJECTS
for	picking up stuff
for	holding; pushing; driving; you can push buttons too.
for	to feel things and hold things and stuff like that.
for	so I can touch things and hold things and draw, and all kinds of stuff.
for	You can pick up things and you can move them and you can touch things with your fingers.
w/o	they couldn't grab anything
w/o	They wouldn't be able to hold things, feel things, or anything like that.
w/o	they wouldn't be able to carry anything
w/o	then they can't hold anything. They need feet to hold things.
w/o	Then they would just be like a little stubby and they couldn't pick anything, except with their feet and their toes, and they have to learn to pick things up with their toes.
w/o	couldn't write or draw or touch or feel

Appendix K: SKIN

LEVEL 0:	DON'T KNOW
for	[don't know]
for	It's for if you fall down maybe skin comes off.
LEVEL 1:	GENERAL BODY FUNCTION
for	hmm... it's for... your heart.
for	bodies
w/o	they would die?
w/o	Then they would really die. [E: They would? Well how come?] Cuz if they don't have um, skin, they'd die.
LEVEL 2:	SPECIFIC BODY FUNCTION
for	so people can't see your blood or bones
for	to cover up your bones and stuff and your blood
w/o	Well, then it would look gross. [E: Well how come?] Because, you'd see all the insides.
w/o	They would be inside-out, and all their body parts would show.
LEVEL 3:	ORGAN/BLOOD CONTAINER; HOLDS TOGETHER
for	to help keep the blood from coming out
for	keep your blood and stuff in
for	So the blood doesn't come out and so your body parts don't fall out, I guess.
LEVEL 4:	PROTECTION; WARMTH
for	to keep you warm

for — for helping germs not to get in all the time.

for — It protects your body from germs. Cuz if you didn't - that's why you have to put a bandaid, so not so many germs can get in. Cuz if you get a cut and you leave it all open and you don't put any cream or anything on it and you don't wash it off, then the germs can get into your blood, and inside you. And you can die.

for — The skin protects the blood and heart and stuff.

for — Your skin protects the flesh, and the flesh protects the bones, and -- No, the flesh protects the muscle, and the muscle protects the bone. The flesh is the -- The skin is the absolute outside of your body.

for — To protect your body parts so there won't be any germs.

for — To protect the inside.

w/o — you wouldn't be able to keep warm

w/o — the germs would just go right in.

w/o — Then all the germs would get inside and then they'd die. They'd get invaded by a germ army.

w/o — then all the germs and dirt would get in you

w/o — They would be cold.

Appendix L: TEETH

LEVEL 0: DON'T KNOW

w/o — [don't know]

LEVEL 1: GENERAL BODY FUNCTION

[N/A]

LEVEL 2: SPECIFIC BODY FUNCTION

w/o — they couldn't talk

LEVEL 3:	CHEWING; EATING; BITING
for	biting
for	eating
for	chewing
for	to chew up food
for	They chew and break up the food you swallow.
for	To help you chew your food.
w/o	couldn't bite
w/o	you won't be able to eat
w/o	couldn't chew

Appendix M: TONGUE

LEVEL 0:	DON'T KNOW
w/o	[don't know]
LEVEL 1:	GENERAL BODY FUNCTION
	[N/A]
LEVEL 2:	SPECIFIC BODY FUNCTION
w/o	you won't rub your teeth
LEVEL 3:	TASTING; TALKING; EATING COMPONENTS
for	for eating and talking
for	the tongue's for licking
for	it's for tasting

for — to move your food around

for — so you can talk and ... so you can do this [clicks his tongue]

for — licking, and... when you talk it moves... in the shape that your words are gonna come out of,... and it um - that's all.

for — Well, it helps you talk, cuz it goes up and down when you talk.

w/o — they couldn't eat

w/o — You wouldn't be able to lick.

w/o — If I didn't have a tongue, this is how I would talk. [talks holding tongue back]. You couldn't eat really, or talk.

w/o — You couldn't taste anything, and also you couldn't even talk.

w/o — Then you couldn't taste anything, and so you'd like everything, cuz it wouldn't taste like anything.

w/o — you couldn't eat. Well, some people can talk without using their tongue. [explains -- means ventriloquists]

CHAPTER 3:

Do Children Reason About Bodily Processes in Terms of a Vitalistic Causal Principle?

3.1. Introduction

Chapter 1 of this thesis introduced the debate among developmental cognitive scientists regarding the nature of children's early understanding of biology. This debate began with Carey's (1985b) claim that before age 10, children's understanding of (what for adults are) biological phenomena does not belong to any biological theory, but is instead conflated with the same theory by which they understand psychological phenomena. In other words, Carey claimed, young children don't understand biological phenomena as "biological" at all, but rather misunderstand them as "psychological", and thus have an undifferentiated psychology/biology theory.

We argued that the question of whether or not a child has a biological theory can be reduced to the question of whether or not the child uses biological explanatory principles to reason about the phenomena in the domain. The real issue in this debate, then, is whether children know any biological causal principles. So far, we have discussed two potential principles -- essentialism (Chapter 1) and biological teleology (Chapter 2). In this chapter, we turn our attention to the final candidate principle posited in the literature for structuring children's first biological theory -- vitalism.

3.1.1. Vitalism -- A Potential Biological Principle

In Carey's (1985b) original formulation of the emergence of children's intuitive biological theory, she contrasted intentional causality (i.e., the psychological causal principle) with mechanistic, physiological causality. In particular, she argued that young children base their explanations of (what for adults are) biological phenomena on intentional causality, and only later (at about age 10) begin to explain biological phenomena in terms of mechanistic causality as adults do. Recently, however, it has been suggested that there may be an alternative, "intermediate" type of explanatory principle which is not exactly intentional, although not yet mechanistic, around which young children may organize an autonomous theory of biology. Inagaki and Hatano (1993; Hatano & Inagaki, 1994) propose that this first causal explanatory principle in biology, or at least for explaining bodily processes, is "vitalism".

As they construe it (Hatano & Inagaki, 1994; Inagaki & Hatano, 1993), vitalism in young children's biology is characterized by the personification of internal organs, whose activities consist of transmitting or exchanging "vital force". This vital force is something which is undifferentiated between substance, energy, and information. In addition, this vitalistic biology purportedly develops from children's tendency to use personification as an analogical mechanism in their bodily reasoning. In other words, what children don't know about an animal, organ, or physiological process, they reason about by analogy to humans, which leads to the idea of organs as "agents", eventually resulting in the notion of vitalistic causality for bodily functions.

Evidence for children's tendency to use person analogy in bodily reasoning comes from three kinds of studies. In the first, 5- and 6-year-old children were asked to make predictions about a rabbit's or grasshopper's behavioral and physiological reactions (Inagaki & Hatano, 1987, 1991). In these studies, children often attributed human characteristics to the animals in determining their predictions (e.g., "We can't keep it [a rabbit] forever in the same size. Because, like me, if I were a rabbit, I would be 5 years old and become bigger and bigger."; Inagaki & Hatano, 1987). In the second, children were simply asked whether or not various animals, plants, and inanimate objects possess certain bodily or physiological properties, such as eating, breathing, or having a heart (Carey, 1985b; Inagaki & Sugiyama, 1988). In these studies, young children tended to underattribute these characteristics to animals other than people, with less attributions occurring the less similar the animal is to people. For example, more children judged that mammals have hearts than that birds do, and more judged that birds have hearts than that bugs do). In the third type of study, young children were taught an unfamiliar property about people (e.g., that they have a spleen), and were asked to project that property to other animals (e.g., "Does a dog have a spleen?"). Analogous to the results in the attribution studies, children's projections dropped off as the animals became more dissimilar to people (Carey, 1985b).

Evidence that children have constructed a vitalistic biology by the age of 6 comes from a study in which 6- and 8-year-old children were asked to choose among three types of causal explanations (i.e., intentional, vitalistic, and mechanistic) for various bodily phenomena (Inagaki & Hatano, 1993). For example, for the question, "Why do we eat food every day?" the explanations offered were: (a) "because we want to eat tasty food" [intentional]; (b) "because our stomach takes in vital power from the food" [vitalistic]; and (c) "because we take the food into our body after its form is changed in the stomach and bowels" [mechanistic]. In this task, the 6-year-olds chose the vitalistic explanations most often (54%), while the 8-year-olds chose the mechanistic explanations most often (62%), followed by the vitalistic explanations (34%).

Based on the results of these experiments, Hatano and Inagaki (1994) argued that vitalism is the first causal explanatory principle children use in their reasoning about bodily phenomena, that it is specific to reasoning about biology, and that it comes from children's tendency to personify biological entities. If this is true, then Inagaki and Hatano (1993; Hatano & Inagaki, 1994) have not only met our qualifications for demonstrating knowledge of a biological principle, and thus the possession of an autonomous biological theory, in children before the age of 10, but they have even supplied us with the means by which children construct this first biology. However, when these claims and data are looked at more closely, several problems with this account become evident.

First, in their discussion of personification, Hatano and Inagaki (1994) conflate the following two analogies: (1) Animals are like people; and (2) Body organs and physiological processes are like people. These are importantly different. While it is almost certainly true that children use the first of these analogies to guide their reasoning about animals, this is rather unremarkable and uninteresting for our current purposes. It simply shows that people are children's prototypical animal (or at least one that they know a lot about), and that they therefore use this to guide inferences about other animals (Carey, 1985b). In fact, it is interesting to note that when children are given sufficient experience with an animal other than people, they analogize to both that familiar animal and to people when predicting the bodily properties of less familiar animals (Kondo & Inagaki, 1991, as cited in Hatano & Inagaki, 1992). The second of these analogies (i.e., that body organs and physiological properties are like people) is the more relevant claim with respect to the vitalism issue, but unfortunately, the personification studies simply don't address this claim.

Second, Inagaki and Hatano's (1993) vitalism study appears to have some methodological problems with the explanations that were offered. Specifically, the intentional explanations were often little more than tautologies (e.g., "We eat food because we want to eat tasty food"), while the mechanistic explanations were often longer and more complex than the other two choices, and sometimes used detailed vocabulary that 6-year-old children are unlikely to know (e.g., "because a sperm and ovum unite..."). Thus, it is possible that the younger children chose the vitalistic explanation so often more because of the unacceptability of the intentional and mechanistic explanations than because of the acceptability of the vitalistic explanation per se.

In sum, while vitalism may be a potential candidate for a causal principle in children's early biological reasoning, the evidence supporting this is rather weak. We would therefore like to see several issues resolved before we accept this principle as children's first biological causal principle. First, we would like a demonstration that Inagaki and Hatano's (1993) results cannot be explained as artifacts of their stimulus choices. Second, we would like to see evidence addressing the question of vitalistic reasoning with children younger than age 6. That is, if 6-year-olds do have a vitalistic biology, is this because vitalism is the manner by which children reason about biological phenomena from the start, or have they instead learned or constructed this vitalistic principle sometime before age 6?

3.2. STUDY 1: Bodily Phenomena

This study examined children's knowledge of bodily processes, in particular with respect to the hypothesis of vitalism as a potential biological causal principle. The task was designed to be a modified replication of Inagaki and Hatano (1993), but with explanations equated for length and complexity. In addition, because we were interested in testing children younger than age 6, several procedural modifications had to be made. First, we used plastic characters rather than fictitious children as the holders of the various beliefs, and gave children the choice of indicating their answers either verbally or by physically moving the characters. Second, rather than hearing all three potential explanations first, and subsequently choosing the best of the three, children were asked to judge each explanation ("good" versus "silly") as it was presented, and were only asked to choose among explanations in those cases where they judged more than one explanation "good". Third, in order to assess the effectiveness of this methodology for tapping children's knowledge of causal explanations, we also presented children with a practice question which had nothing to do with bodily processes, for which we told them the relevant causal information ahead of time.

3.2.1. <u>Method</u>

Subjects

Thirty-six children served as subjects: twelve 4-year-olds (range 4;1 - 4;11; mean = 4;5), twelve 6-year-olds (range 6;2 - 6;11; mean = 6;7), and twelve 8-year-olds (range 8;1 - 8;11; mean = 8;4). Children were recruited from local day care centers and elementary schools, and were mainly from middle class families. Approximately one-third of the children were girls and two-thirds were boys. The data from an additional two children (one 4-year-old and one 8-year-old) were excluded from the study due to their failure to complete both testing sessions.

Design

Children were tested individually in an unoccupied room at their school or day care center. The data for this study were collected as part of a larger study about children's understanding of body parts and processes. Each child participated in two testing sessions, each of which lasted approximately 10 to 20 minutes. The second session was held within two weeks of the first session. In the first session, children completed an interview about body parts (see Chapter 2) and performed some portion of the vitalism task which concerns us here; in the second session children completed the rest of the vitalism task. The current chapter will address only the children's performance in the vitalism task.

Materials

The vitalism interview consisted of six questions concerning bodily phenomena, specifically: drinking, feeling pain, bleeding, healing, dying, and growing. The children were first asked the questions in an open-ended form, and were then presented with potential answers which they were asked to judge as "good" or "silly", and finally (if more than one was "good") to pick which one was "best".

For each question, there were three potential explanations presented, representing each of intentional, vitalistic, and mechanistic explanations. Intentional explanations (I) attributed the phenomenon to the person's intentions, in terms of his or her desires, wishes, or feelings. Vitalistic explanations (V) attributed the phenomenon to the workings of some vitalistic force, described as *energy*, *spirits*, *power*, or *stuff*. Mechanistic explanations (M) attributed the phenomenon to mechanistic, physiological processes occurring within the body. The three types of potential explanations were approximately equal with respect to overall length and complexity. The following are the six questions, with their three accompanying potential explanations.

(1) Do people drink water? Why do they do that -- Why do people drink water? [I] Because if people don't drink water they'll get thirsty, and people don't like to feel thirsty; [V] Because water has energy in it, and people need that energy; [M] Because people's bodies lose water, so they need to replace that water.

(2) If a person were cut with a sharp piece of glass, would they feel pain -- would it hurt? Why is that -- Why do people feel pain? [I] Because noticing the cut makes the person upset, and that makes them feel pain; [V] Because the cut lets bad stuff into the person's body, and bad stuff hurts; [M] Because the nerves near the cut send a pain signal to the person's brain, and that makes them feel pain.

(3) Do you think (if a person were cut) that they would bleed? Why is that -- Why do

people bleed? [I] Because people like bandaids, so they bleed so that they'll get a bandaid; [V] Because the cut needs to be healed, and the blood has healing power that it brings to the cut; [M] Because the cut puts a hole in the skin, and the blood leaks out the hole.

(4) Do you think that cut would be there forever, or would it get better? Why do cuts get better? [I] Because the person wants it to heal, because they don't like how it looks; [V] Because the person's body has energy that will heal the cut; [M] Because new skin grows where the cut was.

(5) Do people die? How come? What makes a person die? [I] Because the person doesn't want to live anymore; [V] Because people have spirits which cause life, and the person's spirit leaves their body; [M] Because the heart beating is important for life, and the person's heart stops beating.

(6) Do people grow? Why -- What makes a person grow? [I] Because the person wants to get bigger, because it's better to be big than small; [V] Because the person gets energy from food that makes them get bigger; [M] Because the person gets stuff from food to build more skin and muscle.

For each question, the three potential explanations were presented to the children as the answers given by three different characters. Three plastic, 5-1/2 inch characters (Cookie Monster, Big Bird, and Ernie) were used toward this end. In addition, two 7-inch plastic buckets were used as the "good" and "silly" buckets in which the characters were placed when the children judged their answers to the questions (see Procedure below). Both the order of the explanation type presented, and the pairing of explanation type with character, were counterbalanced both across questions within children, and across children within a given question.

In addition, to provide a chance for the children to warm-up for the body questions, and as a check that the current methodology was feasible for the youngest children, one practice question not having to do with biological phenomena was presented before the six body questions. For this question, the experimenter first told children a very short story, and then asked them why an event in the story happened. As with the body questions, the practice question was first presented in an open-ended format, and then the children were presented with three potential explanations. Of these explanations, one was causal and in fact true in the story, one was potentially causal but not true in the story, and one was non-causal (See Appendix).

Procedure

After the child completed the body parts interview in Session 1 (see Chapter 2), the experimenter told the child that they were now going to play a game. The experimenter explained that she would first ask the child a question, which the child should answer on his or her own. Then, the experimenter would tell him or her what the three characters said when she had asked them that exact same question, and the child's job was to decide whether each character's answer was good or silly. If the answer was good, then they would put the character in the good bucket; if the answer was silly, then they would put the character in the silly bucket.

The child and experimenter played this game, starting with the non-biology practice question and then moving on to the questions regarding body processes. During the free-explanation, children were given as much time as they needed to answer the question. If children said they didn't know, they were asked to guess. Throughout this game, the children were continually encouraged and told that they were doing well (regardless of their actual answers).

After all three explanations had been judged for a given question, then if the child had judged more than one explanation "good", they were asked to pick the "best" explanation. The experimenter first reminded the child that both of the explanations were good (as they themselves had judged), told the child again what the question was and what each character's explanation was, and then asked them which of those explanations was best. In order to reduce cognitive overload, if all three explanations had been judged "good", then the resulting "best" contest was carried out on only two characters at a time; first with any two of the three, and then with the remaining character versus the winner of the first contest.

During the first testing session, the children completed the practice question plus one to three of the body questions. The number of questions in the first session was flexible, and was decided with respect to how engaged or tired the child appeared to be. During the second session, the children were reminded of the rules of the game, and then completed their remaining questions. For the youngest children (age 4), the practice story and question was also repeated to give them additional warm-up time.

A student colleague made notes of the children's responses, and tape-recorded the sessions. The experimenter later went back and checked the notes against the tape, making changes as necessary.

3.2.2. Results

The results will be presented in three sections. First, we will examine the types of responses children gave in their free explanations. Second, we will examine children's judgments of the various potential explanations as *good* or *silly*. Finally, we will present children's judgments of which explanation was the best answer.

Free Explanations

Children's free explanations were coded into 7 different categories:

(1) Mechanistic: These responses provided a cause for the phenomenon in terms of a body mechanism, and are thus most analogous to the Mechanistic category in the explanation-judgment task (e.g., bleeding because the veins break; dying because the heart stops beating; healing because new skin grows). Note that we did not require that the child provide what we would consider the correct bodily mechanism to be credited with this type of response. For instance, one 4-year-old child was credited with this type of explanation when she explained that growth occurs due to the heart beating.

(2) Vitalistic: These responses attributed the phenomenon to some kind of energy or power, and are thus analogous to the Vitalistic category in the explanation-judgment task (e.g., dying because the heart doesn't have any more energy; healing because the cut has healing power).

(3) Whole Person Characteristic: These responses explained the phenomenon in terms of characteristics of the whole person, rather than due to some specific body part or mechanism (e.g., dying because of getting old or getting sick; growing because of eating or being alive).

(4) External: These responses explained the phenomenon in terms of some cause which was external to the body (e.g., dying due to violence or accidents; healing due to bandaids; pain because the glass was sharp).

(5) Body Function: These responses attributed the phenomenon to fulfilling some specific bodily function (e.g., bleeding cleans the cut; water makes saliva or takes away acid).

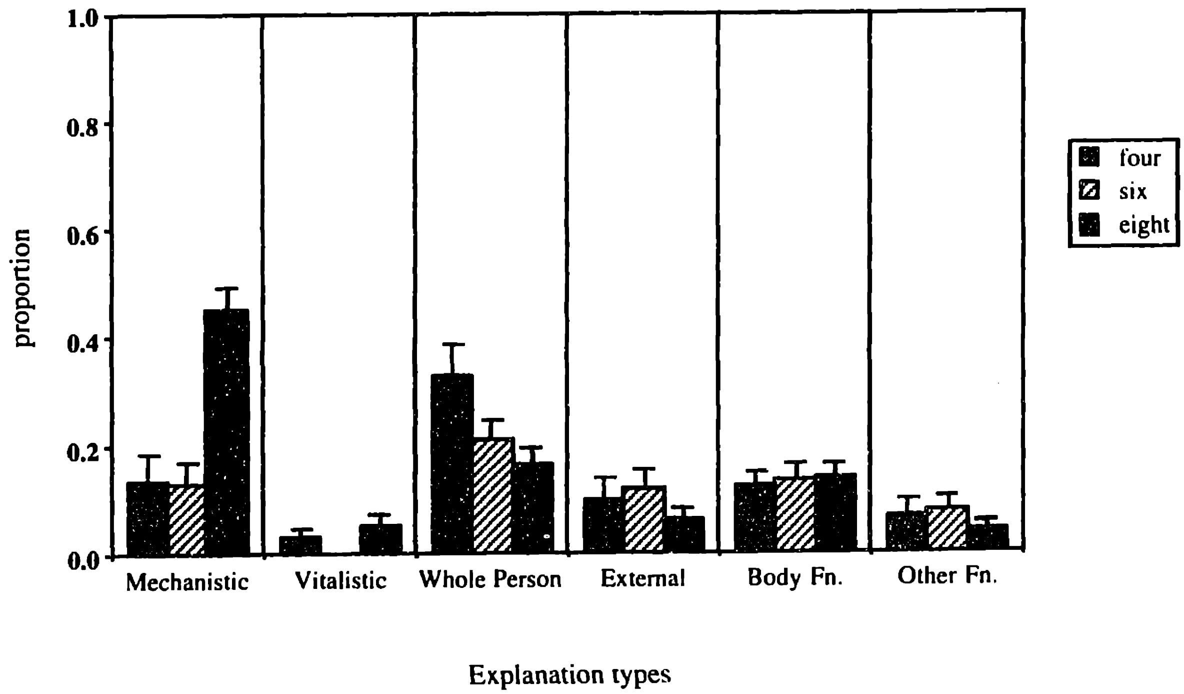
(6) Other Function -- These responses attributed the phenomenon to fulfilling some other (i.e., non-bodily) function (e.g., people die so they'll go to heaven; they grow so they can do more things).

(7) Don't know: The responses in this category included "don't know", uncodable (e.g., people feel pain because glass is plastic) or a restatement of the question without adding new information (e.g., people feel pain because it hurts). This response type was excluded from the following analysis.

If a child gave more than one type of response for a single question, he was credited with each response type that he gave.

The mean proportion of each explanation type given at each age is presented in Figure 3.1. A 3 (age) x 6 (explanation type) mixed Analysis of Variance was performed on these data, with age as the between-subjects factor and explanation type as the within subjects factor. There was a marginal effect of age, F (2, 33) = 3.24, $p < .06$. Specifically, 8-year-olds gave proportionally more codable (i.e., non- "don't know") responses overall than 6-year-olds (Fisher, $p < .05$), while 4-year-olds were not significantly different from either 6- or 8-year-olds. There was also a main effect of explanation type, F (5, 165) = 19.44, $p < .001$. Specifically, *Whole Person Characteristic* and *Mechanistic* explanations were used significantly more often than the other types of explanations overall (Fisher, p's < .05).

Figure 3.1. Mean proportion of different explanation types at each age



In addition, and most important for our current purposes, there was a significant age by explanation type interaction, $F\,(10, 165) = 6.63, p < .001$. In order to probe the reason for this interaction, a series of separate one-way Analyses of Variance were performed for each response type on the proportion of times children gave that response type at each age. There was a significant difference between ages for *Whole Person Characteristic* explanations, $F(2,33) = 3.73$, $p < .04$. In particular, 4-year-olds gave significantly more *Whole Person Characteristic* explanations than did 8-year-olds (Fisher, $p < .05$), while 6-year-olds did not differ significantly from either 4- or 8-year-olds. There was also a significant difference between ages for *Mechanistic* explanations, $F\,(2, 33) = 17.694, p < .001$. In particular, 8-year-olds gave significantly more *Mechanistic* explanations than did 4- and 6-year-olds (Fisher, $p < .05$), while 4- and 6-year-olds did not differ significantly from each other. There were no significant differences between ages for any other explanation types.

In summary, at all ages children gave several different types of explanations for bodily phenomena. Children's tendency to explain bodily phenomena in terms of the characteristics of the whole person (rather than due to some bodily mechanism) decreased between the ages of 4 and 8. In addition, children's *Mechanistic* explanations increased dramatically between the ages of 6 and 8. In contrast, children's *Vitalistic* explanations occurred very rarely, and did not appear to either increase or decrease across the ages studied here. Thus, we have evidence for a mechanistic biological principle appearing between the ages of 6 and 8, but little evidence of autonomous biological reasoning (vitalistic or otherwise) before that time. However, as Inagaki and Hatano (1993) argued, it might be that young children have trouble explicitly generating biological causal explanations, although they have an implicit understanding of them. To explore this possibility, we next turn to children's judgments of potential causal mechanisms.

"Good" Judgments

Our examination of children's "good" (versus "silly") judgments will be broken down into three parts. First, we will look at children's answers to the non-biology practice question, in order to establish that explanation judgments can provide a valid measure of knowledge for young children. Second, we will examine children's responses to the body questions at each age, looking specifically at the patterns of "good" judgments at each age for Intentional, Vitalistic, and Mechanistic explanations. Finally, we will examine children's individual patterns of responding in order to explore whether individual children follow the same patterns of responding that we find at the group level.

Practice Question. Recall that for the practice question, children were first told a story in which the cause of the target event was explicitly stated. One of the potential explanations subsequently presented to the children stated this cause, another stated a different potential cause, and the third potential explanation was non-causal. Thus, the question here was whether this type of explanation judgment task would show evidence of children's causal knowledge when we had specifically given them the necessary causal information. If so, then we would expect similar patterns of responding at all ages. However, if instead 4-year-olds answered randomly or didn't differentiate between the potential explanations, then this would show us that this explanation judgment task would not be a valid measure for assessing their causal knowledge in any domain, and thus could not inform us about their knowledge of biological causal processes.

Figure 3.2. Study 1 -- Non-biology practice question: Proportion of explanations judged "good" at each age

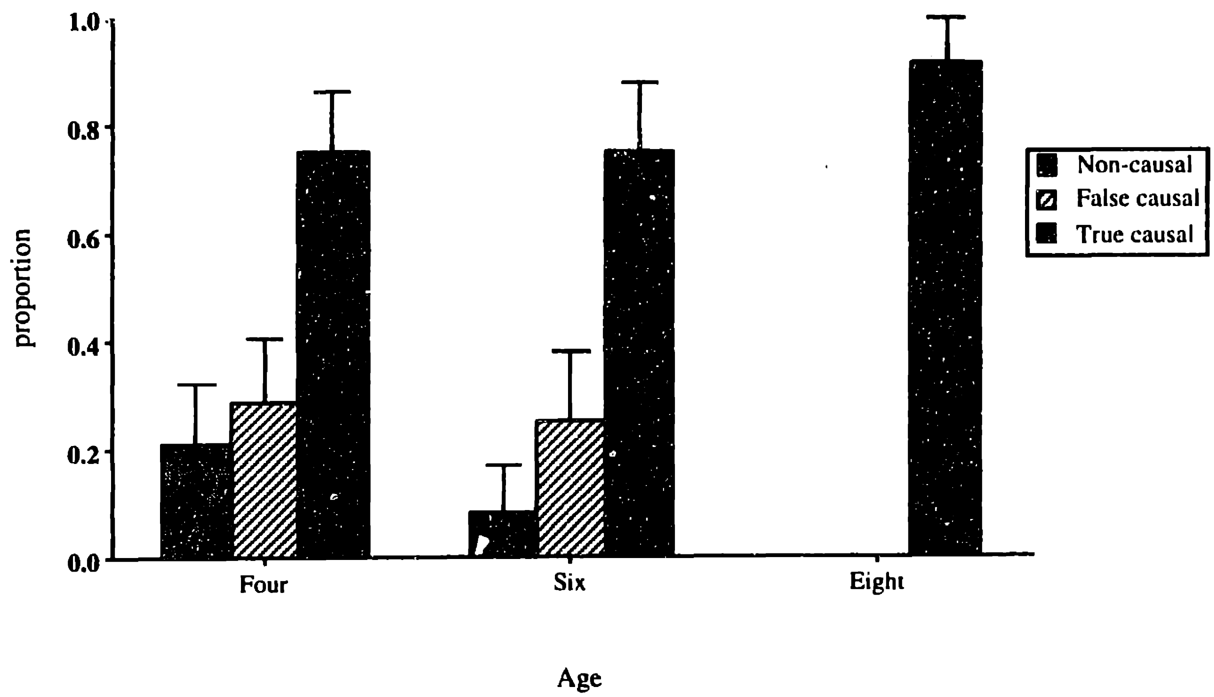


Figure 3.2 presents the proportion of children at each age who judged the different types of explanations "good".[14] As shown in the figure, at all ages children judged the correct causal explanation "good" more often than either of the other two potential explanations. A 3 (age) x 3 (explanation) mixed Analysis of Variance on these data showed a main effect of explanation type, $F(2, 66) = 34.98, p < .001$, such that the true causal explanation was judged "good" significantly

[14] Because this question was repeated twice in the case of 4-year-olds (once in each session), their score was calculated as the mean of their answers on both occasions. However, the same results are obtained when the data are analyzed using the 4-year-olds' responses from just the first session.

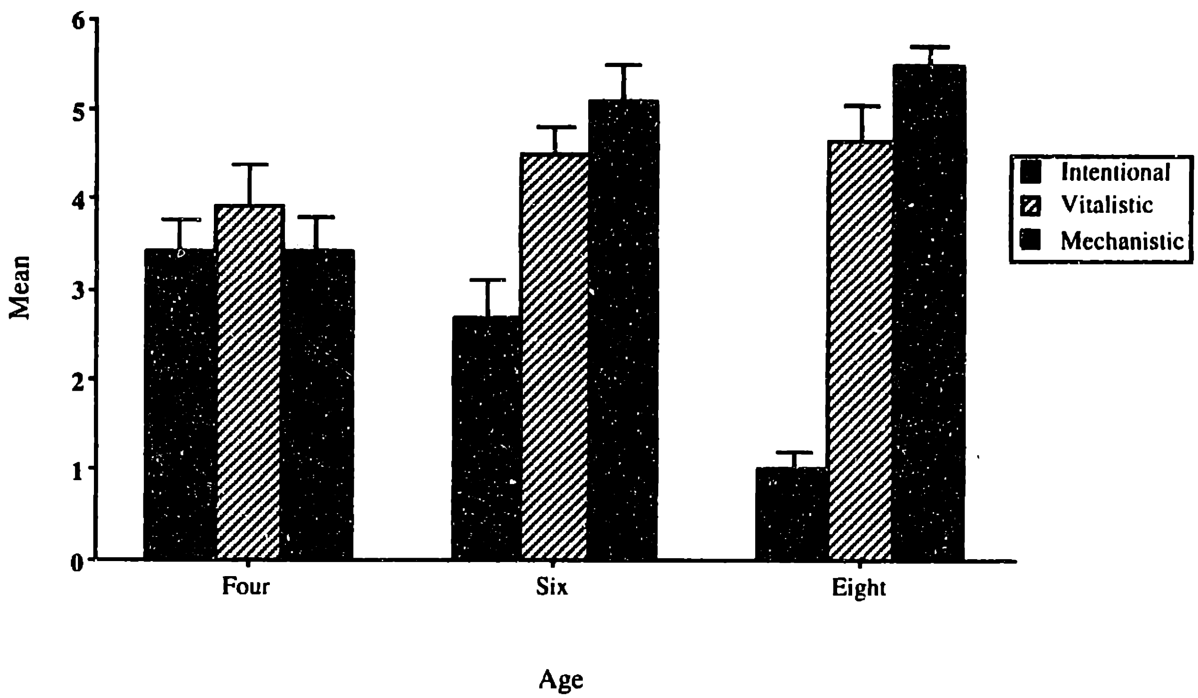
more often than either the false causal or non-causal explanation (Fisher, p's < .05). There was also a marginal effect of age, $F(2, 33) = 2.69$, $p < .09$, such that 4-year-olds judged more explanations "good" overall than the 8-year-olds did (Fisher, $p < .05$). The 6-year-olds were not significantly different from either the 4- or the 8-year-olds. Most importantly for our purposes, however, there was no significant interaction between age and explanation type ($p > .24$). In other words, when given the same background information, there was no difference between ages in their pattern of responding in the current task. We may thus feel confident in assuming that the explanation judgment task provides an accurate window into even 4-year-old children's explanatory knowledge.[15]

Group responses. We now turn to children's judgments of potential explanations of bodily phenomena. Recall that children were presented with three potential explanations for each question, representing each of intentional, vitalistic, and mechanistic explanations. Intentional explanations attributed the phenomenon to the person's intentions, in terms of his or her desires, wishes, or feelings. Vitalistic explanations attributed the phenomenon to the workings of some vitalistic force, described as *energy*, *spirits*, *power*, or *stuff*. Mechanistic explanations attributed the phenomenon to mechanistic, physiological processes occurring within the body.

Figure 3.3 shows the mean number of Intentional, Vitalistic, and Mechanistic explanations that were judged "good" at each age.

[15] As a further check on this, we compared the results on the body questions of 4-year-olds who performed perfectly on the practice question versus those who did not (see later analyses). There were no significant differences between groups (p's > .59)

Figure 3.3. Study 1 -- Mean number of explanations judged "good" at each age



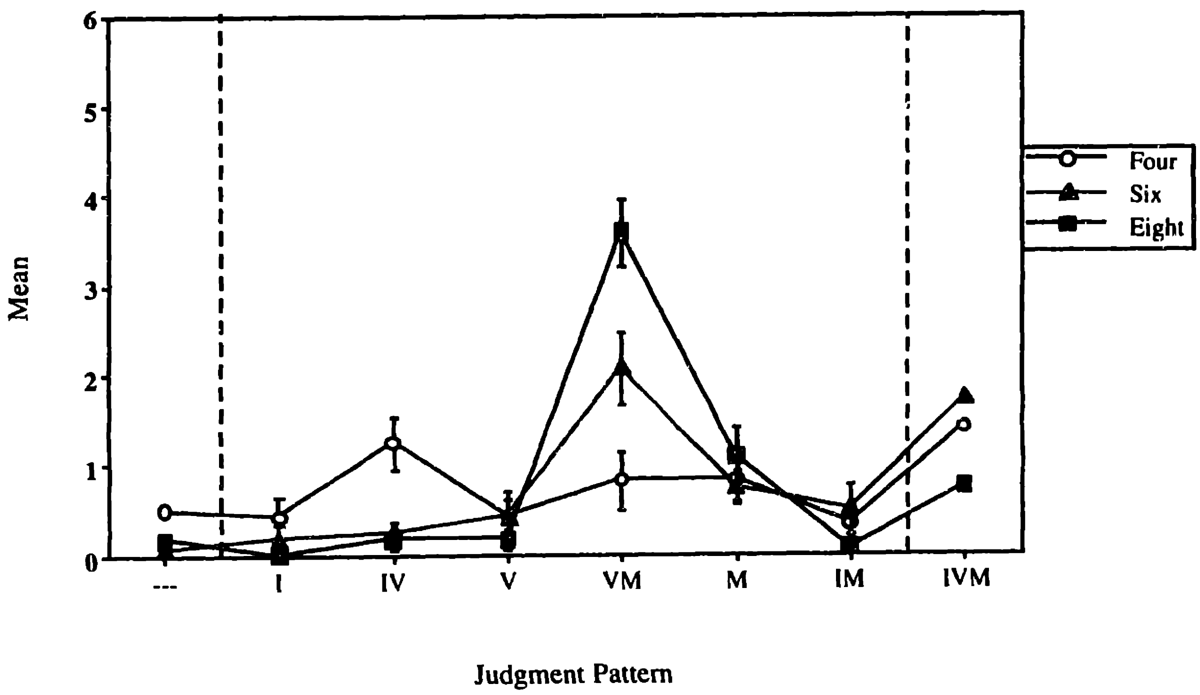
A 3 (age) x 3 (explanation) mixed Analysis of Variance was performed on the number of "good" judgments children gave for each type of explanation (possible range: 0 - 6). There was no main effect of age. There was, however, a significant main effect of explanation type, F (2, 66) = 43.52, $p < .001$, and also a significant interaction between age and explanation type, F (4, 66) = 12.49, $p < .001$. To explore this interaction further, separate one-way Analyses of Variance were performed for each age group on the number of "good" judgments children gave for each type of explanation. For 4-year-olds, there were no significant differences between explanation types ($p >$ .53). That is, 4-year-old children judged each explanation type "good" equally often (about 60%). In contrast, there were significant differences between explanation types for both 6-year-olds, F (2, 22) = 11.72, $p < .001$, and 8-year-olds, F (2, 22) = 100.13, $p < .001$. Both of these age groups judged Vitalistic and Mechanistic explanations "good" significantly more often than Intentional explanations (Fisher, p's < .05). In addition, the 8-year-olds judged Mechanistic explanations "good" significantly more often than Vitalistic explanations (Fisher, $p < .05$).

An alternative way of looking at these data involves the pattern of judgments that children gave for each question. For example, did the judgments of the older children reflect the belief that Vitalistic and Mechanistic explanations were both good explanations for the same phenomenon, or rather simply that Intentional explanations were not good explanations of that phenomenon? This type of worry is particularly important with respect to the 4-year-olds. If, for example, they judged that both Vitalistic and Mechanistic explanations were good for half of the phenomena, while only Intentional explanations were good for the remaining half, then this regularity in judgment would be masked in the previous analysis, where it would instead manifest itself as a random pattern.

There are eight potential judgment patterns possible, ranging from none of the three explanations judged "good" to all of the explanations judged "good", with six intermediate patterns in between (e.g., only Intentional and Vitalistic judged "good", only Mechanistic explanations judged "good", etc.). The intermediate steps (i.e., those not judged either all good or all bad) are the most interesting ones for our purposes. The question is this -- when children differentiate between explanation types, which explanation or set of explanations do they prefer?

Figure 3.4 presents the number of "good" judgments belonging to each of the six possible intermediate pattern types at each of the three different ages. (For the sake of completeness, the non-intermediate pattern types are also presented on either side of the broken lines; they are not included in the analysis). Because Vitalistic causality is supposed to represent an intermediate step between Intentional and Mechanistic causalities (Inagaki & Hatano, 1993), the categories are arranged as such in the figure. Thus the graph roughly represents an ordering moving from strictly Intentional to strictly Mechanistic as you move from left to right. (Note that the IM pattern does not fall along this theoretical continuum; it was included after the M pattern for completeness).

Figure 3.4. Study 1 -- Mean number of explanations judged "good" by pattern of judgments



A 3 (age) x 6 (judgment pattern) mixed Analysis of Variance on these data revealed a significant main effect of judgment pattern, F (5, 165) = 25.22, $p < .001$, and a significant interaction between age and judgment pattern, F (10, 165) = 7.19, $p < .001$. To determine the cause of this interaction, separate one-way Analyses of Variance were performed for each age on the number of judgments falling into each pattern. For 4-year-olds, there were no significant differences between judgment patterns. In contrast, there were significant differences between judgment patterns for both the 6-year-olds, F (5, 55) = 6.93, $p < .001$, and the 8-year-olds, F (5, 55) = 34.92, $p < .001$. Specifically, the 6-year-olds had significantly more judgments in the VM pattern (i.e., both Vitalistic and Mechanistic explanations judged "good") than in any of the other patterns (Fisher, p's < .05). The 8-year-olds also had significantly more judgments falling into the VM pattern than into any of the other patterns (Fisher, p's < .05), but in addition had significantly more judgments in the M pattern (i.e., only Mechanistic explanations judged "good") than in any of the other patterns save VM (Fisher, p's< .05).

This analysis thus clarifies the results from the previous analysis. The shift in responding between ages 4 and 6 is best characterized as one from random responding to systematic responding which is not simply driven by the belief that Intentional explanations are not good. (If that were the case, the "good" judgments would presumably be spread somewhat between the Vitalistic-only, Mechanistic-only, and Mechanistic + Vitalistic judgment patterns.) Rather, this systematicity seems based on a preference for both Vitalistic and Mechanistic explanations. This preference then becomes further amplified by age 8, along with an additional preference for just Mechanistic explanations.

Individual patterns. In order to explore whether the patterns found at the level of group responses are accurate characterizations of the responses of individual children, we also examined children's individual patterns of responding. We counted a child as responding positively to a particular judgment pattern if more than two-thirds of their judgments exemplified it. (That is, for each explanation type considered positive in that pattern, 5 or 6 of the explanations had to be judged "good".) In principle, then, it is possible for a child to exhibit any of the eight possible patterns of responding of the previous analysis (e.g., none [i.e., "inconsistent" judgments], Intentional-only, Intentional + Vitalistic, Vitalistic-only, etc.). In actuality, none of the children qualified as Intentional-only responders. The number of children belonging to each of the remaining seven categories is presented in Table 3.1.

Table 3.1. "Good" judgments: Number of children in each response group at each age.

	Four	Six	Eight
inconsistent	5	1	0
IV	1	0	0
V	3	1	1
VM	0	6	6
M	1	3	5
IM	1	1	0
IVM	1	0	0

For purposes of analysis, a chi-square was performed on the number of children at each age classified as inconsistent versus one of the other consistent response categories. There was a significant difference between ages, χ^2 (2) = 8.40, $p < .02$. Specifically, the 4-year-olds were significantly different from the 8-year-olds, χ^2 (1) = 6.32, $p < .02$, and marginally significantly different from the 6-year-olds, χ^2 (1) = 3.56, $p < .06$, while the 6-year-olds and the 8-year-olds were not significantly different from each other ($p > .30$). At age 4, almost half of the children showed no consistent positive response for any of the explanation types, and none of the children showed the VM pattern (i.e., consistent positive responses to both Vitalistic and Mechanistic explanations). In contrast, at both ages 6 and 8, fully half of the children showed the VM pattern, and only one child showed inconsistent responses. In addition, there also seems to be a growing preference for the M pattern (i.e., consistent positive responses to only the Mechanistic explanations) with increasing age, with only one child showing this pattern at age 4, three children at age 6, and five children at age 8. Thus, we again see a shift in responses between ages 4 and 6 [inc --> VM], with further differentiation happening between ages 6 and 8 [VM --> VM + M].

Summary. When measured by children's "good" judgments of different types of explanations, rather than by their own freely generated explanations, we find a previously masked shift in children's bodily reasoning between the ages of 4 and 6. Specifically, the 4-year-olds show no consistent pattern of preferences among the explanations, while the 6-year-olds show a marked preference for both Vitalistic and Mechanistic explanations. At age 8, this preference for both Vitalistic and Mechanistic explanations remains strong, but in addition we see a further preference for Mechanistic explanations over Vitalistic ones.

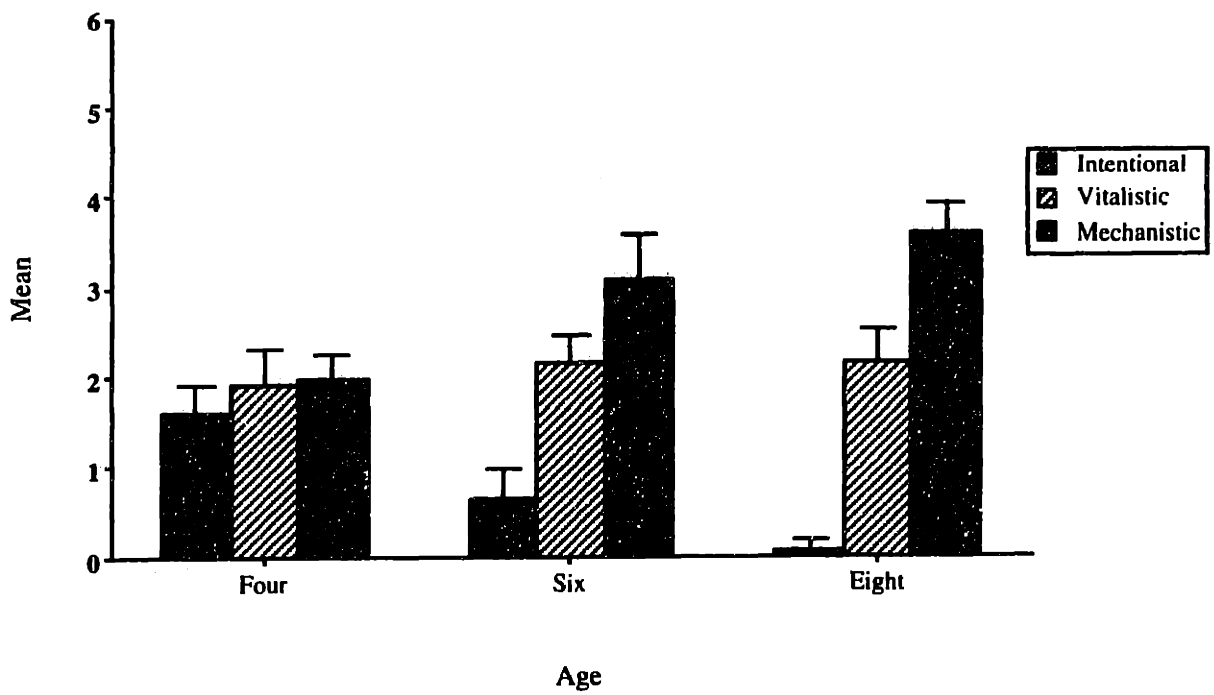
"Best" Judgments

Finally, we turn to children's choices regarding which of the three potential explanations was the "best" one. There were two ways in which an explanation could be counted as "best": (1) If a child judged that only one of the three explanations was "good", then that solitary "good" explanation was also considered the "best"; (2) If a child specifically picked that explanation to be "best" out of two or more "good" explanations. Note that there were a few cases in the latter instance where a child refused to pick a single "best" explanation, but rather insisted that both of them were "best" (i.e., equally good). In these cases, we gave each of these explanations half-credit for being the "best".

Group responses. Figure 3.5 shows the mean number of Intentional, Vitalistic, and Mechanistic explanations that were judged "best" at each age.[16]

[16] Columns do not always add to 100% because of some children's judgments that none of the offered explanations were good.

Figure 3.5. Study 1 -- Mean number of explanations judged "best" at each age



A 3 (age) x 3 (explanation) mixed Analysis of Variance was performed on the number of "best" judgments children gave for each type of explanation (possible range: 0 - 6). There was a significant main effect of explanation type, F (2, 66) = 19.5, $p < .001$, and also a significant interaction between age and explanation type, F (4, 66) = 3.83, $p < .01$. To explore this interaction further, separate one-way Analyses of Variance were performed for each age group on the number of "best" judgments children gave for each type of explanation. For 4-year-olds, there were no significant differences between explanation types ($p > .80$). That is, 4-year-old children judged each explanation type "best" equally often (about 31%). In contrast, there were significant differences between explanation types for both 6-year-olds, F (2, 22) = 6.67, $p < .01$, and 8-year-olds, F (2, 22) = 23.42, $p < .001$. Both of these age groups judged Vitalistic and Mechanistic explanations "best" significantly more often than Intentional explanations (Fisher, p's < .05). In addition, the 8-year-olds judged Mechanistic explanations "best" significantly more often than

Vitalistic explanations (Fisher, $p < .05$).

Individual patterns. As with the "good" judgments, we also looked at children's individual patterns of responding to see if individual patterns replicated group patterns. We counted a child as favoring a particular type of explanation if over half of those explanations were judged "best" by the child (i.e., 3.5 or more out of 6). The children who did not favor any of the response types in this manner were counted as Inconsistent. In principle, then, it is possible for a child to belong to any of four different response categories: Intentional, Vitalistic, Mechanistic, or Inconsistent. In actuality, none of the children qualified as Intentional responders, thus leaving us with three remaining categories. The number of children falling into each of these three categories is presented in Table 3.2.

Table 3.2. "Best" judgments: Number of children in each response group at each age.

	Four	Six	Eight
Inconsistent	9	5	3
Vitalistic	2	1	2
Mechanistic	1	6	7

For purposes of analysis, a chi-square was performed on the number of children at each age classified as inconsistent versus one of the other consistent response categories. There was a significant difference between ages, χ^2 (2) = 6.24, $p < .05$. Specifically, the 4-year-olds were significantly different from the 8-year-olds, χ^2 (1) = 6.00, $p < .02$, and marginally significantly different from the 6-year-olds, χ^2 (1) = 2.74, $p < .10$, while the 6-year-olds and the 8-year-olds were not significantly different from each other ($p > .38$). This pattern can presumably be explained by the fact that at age 4, three-fourths of the children were classified as inconsistent responders, while this number dropped to less than half by age 6, and further to one-third by age 8. Conversely, the number of Mechanistic responders jumped from one at age 4, to at least half of the children at ages 6 and 8.

Summary. When measured by children's choices of the "best" among different types of explanations, we again find a shift in children's reasoning about bodily phenomena between the ages of 4 and 6. Specifically, 4-year-olds showed no consistent pattern of responding at either the level of the group or of the individual. In contrast, 6-year-olds preferred both Vitalistic and Mechanistic explanations to Intentional ones at the group level, and showed a further preference for Mechanistic over Vitalistic explanations at the individual level. Finally, 8-year-olds showed a consistent pattern of preferring Mechanistic over Vitalistic over Intentional explanations, as measured at both the group and individual level.

3.2.3. Discussion of Study 1

Whether assessed by their judgments of the "goodness" of explanations, or by their choice of the "best" among several explanations, 4-year-old children showed no consistent pattern of responses. That is, they did not differentiate among Intentional, Vitalistic, and Mechanistic explanations, but rather judged them all as equally "good" or "best". This chance performance of the young children is perhaps best explained by positing that they simply did not know the type of causal information that was relevant for the phenomena in question (i.e., bodily processes); in other words, that they had no biological causal principles. Supporting this assertion is the fact that for the question on which they were supplied with the relevant causal information (i.e., for the non-biology practice question), the performance of 4-year-old children was not different from that of their older counterparts.

In contrast to the chance responding of the 4-year-olds, 6-year-old children were remarkably consistent in their choices. Whether measured by overall number of "good" judgments, pattern of "good" judgments for individual questions, pattern of "good" judgments for individual children, or overall number of choices of the "best" explanation, 6-year-olds clearly showed a preference for <u>both</u> Vitalistic and Mechanistic explanations. We are thus forced into positing either that two separate biological causal principles appear at the same time as the "first" causal principles, or that both of these explanation types somehow tap the same underlying causal principle. In addition, in what seems a foreshadowing of the results found with the 8-year-olds, when 6-year-olds were put into the forced-choice categories of liking either Vitalistic or Mechanistic explanations best, half of the children were classified as Mechanistic responders, while only one child was classified as a Vitalistic responder. Thus, although our results indicate that 6-year-old children have an autonomous biological theory, they do not corroborate Inagaki and Hatano's (1993) conjecture that this theory is vitalistic rather than mechanistic.

Finally, the 8-year-olds also preferred both Vitalistic and Mechanistic explanations, but in addition showed evidence of a shift toward preferring Mechanistic over Vitalistic explanations (shown most clearly in their judgments of which one makes the "best" explanation). This shift in explanation choices and judgments was echoed in the results of the free explanations, where there was a dramatic increase in Mechanistic explanations between 6 and 8 years of age. Inagaki and Hatano (1993) also noted a similar shift between the ages of 6 and 8, which they characterized as a shift from a vitalistic to a mechanistic biological theory. The question is thus not whether such a shift occurs, but how best to characterize and explain that shift. We will return to this issue in the general discussion.

Our argument for a dramatic shift in biological understanding between the ages of 4 and 6 is based largely on the fact that the performance of 4-year-olds was at chance levels. However, there are two possible reasons for this failure to differentiate among explanations. One reason might be that they simply did not know the type of causal information that was relevant for the phenomena in question (this is the argument we made above). However, another possibility is that the task was simply too difficult for them. If that were true, then we would expect them to show chance responding even in cases where they did know the relevant causal information.

We attempted to control for this possibility with the non-biology practice question, in which we supplied children with the relevant causal information. In doing so, however, it is possible that we changed the fundamental nature of the task. To succeed at the practice question, children simply had to decide that the correct explanation which had been supplied to them just moments before was in fact a "good" explanation. This is perhaps different than judging potential explanations in a situation where the exact correct explanation has not been explicitly supplied.

Study 2 controls for this possibility. The same task structure is followed as in Study 1, but using questions concerning physical rather than bodily phenomena. Therefore, if 4-year-olds succeed at this task (by differentiating between various explanations) then we may safely conclude that their failure in Study 1 was due to the domain of inquiry (i.e., biology) rather than to the structure of the task itself.

3.3. STUDY 2: Physical Phenomena

3.3.1. Method

Subjects

Twelve 4-year-old children served as subjects (range 4;0 - 5;0; mean = 4;7). Children were recruited from local day care centers, and were mainly from middle class families. Half of the children were girls and half were boys. Children were tested individually in an unoccupied room at their day care center.

Materials

The interview consisted of four questions concerning physical phenomena: stepping off of a rock; stepping on an egg; shooting an arrow at a tree; and attempting to lift a house. As in Study 1, the children were first asked the questions in an open-ended form, and were then presented with potential answers which they were asked to judge as "good" or "silly", and finally (if more than one was "good") to pick which one was "best".

For each question, there were three potential explanations presented, representing each of mechanistic, intentional, and irrelevant explanations. Mechanistic explanations (M) explained the phenomenon in terms of simple, intuitive physical causes. Intentional explanations (IN) attributed the phenomenon to the person's intentions, in terms of his or her desires, wishes, or feelings. Irrelevant explanations (IR) explained the phenomenon in terms of some irrelevant attribute of the situation. The three types of potential explanations were approximately equal with respect to overall length and complexity. The following are the four questions, with their three accompanying potential explanations.

(1) If a person stepped off a big rock, would they go up into the air or down onto the ground? Why would they go down onto the ground? [M] Because they're heavy, and heavy things go down; [IN] Because they like being on the ground better than they like being in the air; [IR] Because there's grass on the ground, and grass makes them go down.

(2) If a very big person accidentally stepped on an egg, would it break? Why would it break? [M] Because the egg was too weak to hold the person up; [IN] Because the person wanted it to break, because they like messy things; [IR] Because the egg was white, and white things break easily.

(3) If a person shot an arrow at a tree (just right), would it stick to the tree, or would it always fall to the ground instead? Why would it stick to the tree? [M] Because the arrow has a very sharp point that goes into the tree; [IN] Because the person wishes the arrow will stick to the tree; [IR] Because the arrow is brown, so it sticks to the tree.

(4) If a small boy tried to lift up a house, could he do it? Why not? [M] Because the house is too heavy, and the boy isn't strong enough to lift it; [IN] Because he didn't really want to lift it, because that wouldn't be much fun; [IR] Because it's a cloudy day, and that makes it hard to lift things.

The characters and buckets used were the same as in Study 1. Again, both the order of the explanation type presented, and the pairing of explanation type with character, were counterbalanced both across questions within children, and across children within a given question. In addition, the same warm-up story and practice question as used in Study 1 was presented before the four physical reasoning questions (See Appendix).

Procedure

The procedure was identical to the procedure used in Study 1.

3.3.2. Results

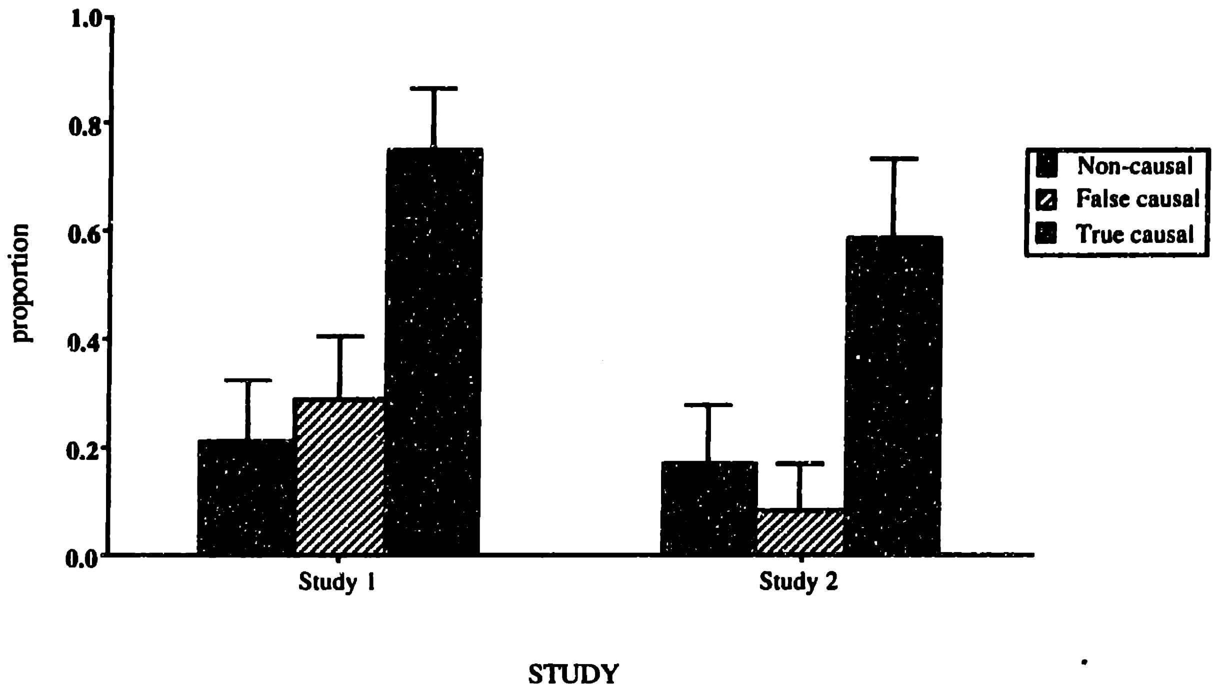
The results will be presented in three sections. First, to ensure the comparability of the children in Studies 1 and 2, we will compare 4-year-olds' performance on the practice question across studies. Second, we will examine children's judgments of the various potential explanations as good or silly. Finally, we will present children's judgments of which explanation was the best answer.

Practice Question.

Recall that for the practice question, children were first told a story in which the cause of the target event was explicitly stated. One of the potential explanations subsequently presented to the children stated this cause, another stated a different potential cause, and the third potential explanation was non-causal. Figure 3.6 shows the proportion of 4-year-olds in each study who judged the different types of explanations "good".[17]

[17] Because this question was repeated twice in the case of the 4-year-olds in Study 1 (once in each session), their score was calculated as the mean of their answers on both occasions. However, the same results are obtained when the data are analyzed using their responses from just the first session.

Figure 3.6. Comparison of 4-year-olds on practice question: Proportion of explanations judged "good" in each study

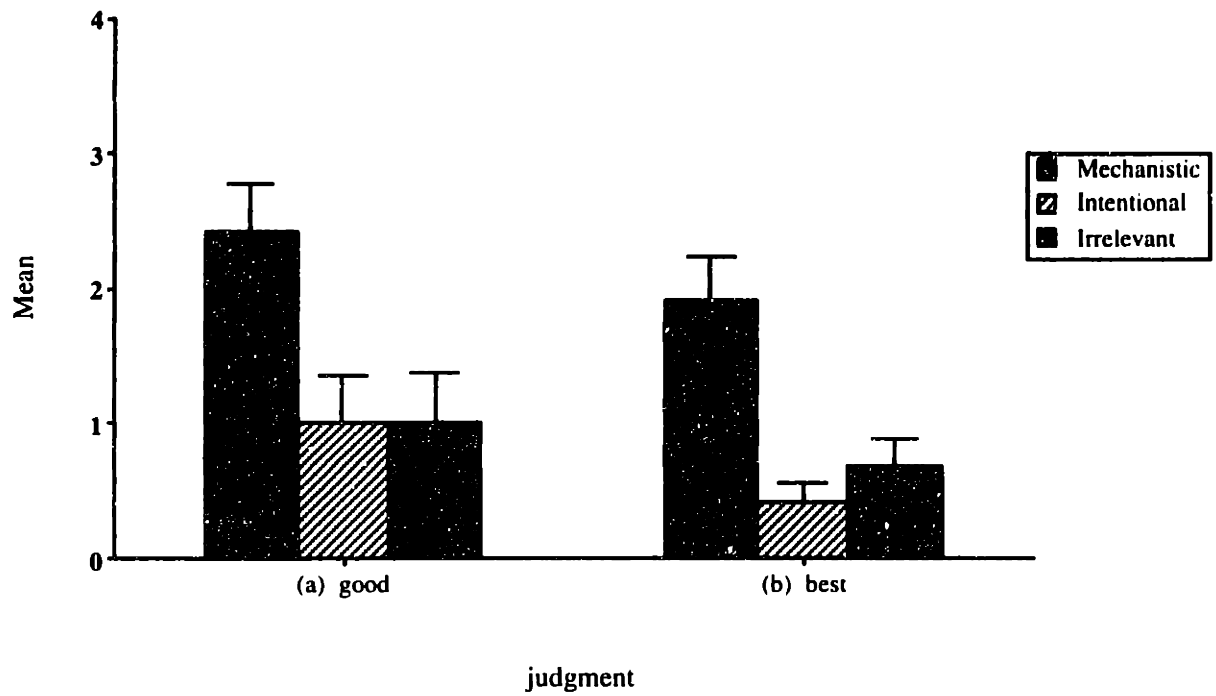


As shown in the figure, the 4-year-old children in both studies chose the correct causal explanation more often than either of the other two explanations. A 2 (study) x 3 (explanation) mixed Analysis of Variance on these data showed a main effect of explanation type, $F(2, 44) = 9.25$, $p < .001$, such that the true causal explanation was chosen significantly more often than either the false causal or non-causal explanation (Fisher, p's $< .05$). There was also a marginal effect of study, $F(1, 22) = 3.87$, $p < .10$, such that the 4-year-olds in Study 1 judged more explanations "good" overall than the 4-year-olds in Study 2 did (Fisher, $p < .05$). Most importantly for our purposes, however, there was no significant interaction between study and explanation type ($p > .79$). We may thus feel confident in assuming that the children in Studies 1 and 2 are roughly comparable.

"Good" Judgments

Figure 3.7(a) shows the mean number of Mechanistic, Intentional, and Irrelevant explanations that were judged "good". A one-way Analysis of Variance was performed on the number of "good" judgments children gave for each type of explanation (possible range: 0 - 4). There was a significant effect of explanation type, $F\,(2, 22) = 8.85, p < .01$. Specifically, the children judged the Mechanistic explanations "good" significantly more often than Intentional and Irrelevant explanations (Fisher, $p < .05$). There was no significant difference between Intentional and Irrelevant explanations.

Figure 3.7. Study 2 -- Mean number of explanations judged "good" and "best"



"Best" Judgments

Next, we turn to children's choices regarding which of the three potential explanations was the "best" one. As in Study 1, there were two ways in which an explanation could be counted as "best": (1) If a child judged that only one of the three explanations was "good", then that solitary "good" explanation was also considered the "best"; (2) If a child specifically picked that explanation to be "best" out of two or more "good" explanations.

Figure 3.7(b) shows the mean number of Mechanistic, Intentional, and Irrelevant explanations that were judged "best".[18] A one-way Analysis of Variance was performed on the number of "best" judgments children gave for each type of explanation (possible range: 0 - 4). There was a significant effect of explanation type, $F(2, 22) = 8.32, p < .01$. Specifically, the children judged the Mechanistic explanations "best" significantly more often than Intentional and Irrelevant explanations (Fisher, $p < .05$). There was no significant difference between Intentional and Irrelevant explanations.

3.3.3. Discussion

In their judgments of both "good" and "best" explanations for physical phenomena, 4-year-old children clearly differentiated between Mechanistic, Intentional, and Irrelevant explanations. Specifically, they consistently chose that Mechanistic explanations were good explanations for physical phenomena, while Intentional and Irrelevant explanations were not. This pattern is markedly different from the chance responding that characterized the performance of the 4-year-olds on questions dealing with bodily phenomena (Study 1). This shows that the explanation judgment methodology is not inherently too difficult for 4-year-olds to perform, and therefore supports the contention that the 4-year-olds' chance responding in Study 1 was simply the result of their not knowing the relevant biological causal mechanisms.

3.4. General Discussion

The results of this study support the claim that young children have knowledge of a biological causal principle, and thus possess an autonomous theory of biology, by 6 years of age (Hatano & Inagaki, 1994; Inagaki & Hatano, 1993). In spite of this basic agreement, however, the current results also differ from those of Inagaki and Hatano (1993) in some important respects. First, our results showed a clear and dramatic shift in children's explanatory preferences between 4

[18] The columns do not add to 100% because of some children's judgments that none of the offered explanations were good.

and 6 years of age. Since the youngest children in Inagaki and Hatano's (1993) experiment were 6-year-olds, they were not in any position to find such an age shift. Second, we did not find evidence that the child's biological theory is "first vitalistic; then mechanistic". Rather, as soon as children showed any differentiation among the explanations (i.e., at age 6), they clearly showed a preference for both Vitalistic and Mechanistic explanations. Thus, although our results indicate that 6-year-old children have an autonomous biological theory, they do not corroborate Inagaki and Hatano's (1993) conjecture that this theory is vitalistic rather than mechanistic.

There are a number of possible explanations for this difference between the studies. One explanation has to do with procedural differences. First, recall that in Inagaki and Hatano's (1993) experiment, the mechanistic explanations were often longer and more complex than the other two choices. We argued that this may have made these explanations unattractive to the younger children. If this is true, then the fact that the current study controlled for overall length and complexity of explanations may have had the effect of making the mechanistic explanations more acceptable to the younger children. Second, in Inagaki and Hatano's experiment, children were asked to choose among the three explanations. In the current study, children were first asked to judge each explanation as it was presented ("good" versus "silly"). These acceptability judgments allowed us to see very clearly that children believed that both vitalistic and mechanistic explanations were good explanations at ages 6 and 8.

Another possible explanation for this difference between the studies may stem from the differences between the Japanese and American cultures. That is, in Japan, a large proportion of the adult population subscribes to an explicitly vitalistic folktheory of biology in which internal organs are endowed with agency, and function to maintain bodily harmony via the transmission and exchange of vital energy. In addition, the Japanese language has a word referring to this vital energy ("ki"). In contrast, the standard American folktheory of biology is not so obviously vitalistic, and the English language has no analogous word. Thus, the difference between our 6-year-olds and those in Inagaki and Hatano (1993) may reflect the effect of differences between the adult theories in the two cultures, or differences in the language used, or both.

According to the current study, the development of children's biological reasoning can be described as follows: First, during the preschool years, children simply have no knowledge of any causal principles which would be relevant to biological phenomena. Thus, although they may be able to distinguish between animals and non-animals, and between physical/physiological and social/psychological phenomena (e.g., Backscheider et al., 1993; Inagaki & Hatano, 1993; Keil, 1989, 1992, 1994; Rosengren et al., 1991; Siegal, 1988; Springer, 1992; Springer & Keil, 1989, 1991; Springer & Ruckel, 1992), these distinctions are presumably made either on the basis of their knowledge in the psychological and social domains, or perhaps on the basis of domain-general principles for the acquisition of factual knowledge, rather than on the basis of any biological knowledge. In addition, our results cast doubt on the claim that young children ever understand biological processes in psychological terms (Carey, 1985b). The young children in this study offered no Intentional mechanisms in their free explanations, nor did they judge Intentional mechanisms as "good" or pick them as "best" at any greater rate than Vitalistic or Mechanistic explanations. Thus, it would seem that not only do preschool-age children not have an autonomous biological theory (i.e., separated from psychology), but they may not have any framework theory in which to place biological phenomena at all.

Next, by around age 6, children appear to have knowledge of at least one biological causal principle, and therefore pass our test for possessing an autonomous biological theory. As stated above, however, we do not find that their biological theory is first vitalistic, and then later becomes mechanistic (contrary to Inagaki and Hatano [1993]). Rather, it appears that vitalism and mechanism come in simultaneously, and then continue to remain "good" explanations for children at least through the age of 8. The most parsimonious explanation for this pattern is that both of these explanation types are based upon the same underlying causal principle, and it is this causal principle, could we characterize it correctly, that underlies children's judgments of what makes a "good" explanation for biological phenomena.

Given this state of affairs, the obvious question arises as to what exactly the difference is between vitalistic and mechanistic explanations in the first place. In other words, is it possible to talk about Vitalism and Mechanism as two separate principles, or are they instead necessarily manifestations of the same underlying principle? As we construe it, the hallmark of a vitalistic theory is the belief that bodily processes cannot be reduced to purely physical or chemical processes. Note that this is not the same as denying that physical or chemical processes exist in biological systems, or that they indeed play a crucial role in bodily function. Rather, a vitalistic theory is simply committed to the fact that there is some additional causal force which affects the workings of these physico-chemical processes[19]. This additional causal force has been known as *life force*, *vital force*, *ki*, *entelechies*, *soul*, etc. A mechanistic theory, on the other hand, while agreeing that physical and chemical processes play a crucial role in bodily processes, remains committed to the idea that these processes constitute the full explanation for all body processes -- that is, there is no "additional" force at work.

In light of this analysis, then, it seems questionable whether our task in fact accurately tapped this difference between vitalistic and mechanistic theories. That is, while it is rather noncontentious to claim that appealing to energy or power is indicative of a vitalistic theory, it is rather more contentious to claim that appealing to ostensibly more "mechanistic" explanations involving such things as skin growing and hearts pumping is necessarily non-vitalistic. To reiterate, what makes a mechanistic theory mechanistic is not simply that it appeals to mechanistic processes -- both mechanistic and vitalistic theories do this. Rather, what makes a mechanistic theory mechanistic is that, when pushed to its most fundamental level, it "bottoms out", or reduces, to only mechanistic processes. Thus, while the current results support the conclusion that the 6-year-old theory is vitalistic in nature, they do not necessarily support the further conclusion that the 8-year-old theory is non-vitalistic (i.e., mechanistic).

So how can we characterize children's early biological theory? As noted in the previous chapter, by about age 6, children construct the idea of "Life" as a teleological bodily goal. We suggest that with this comes the idea that physiological mechanisms function to move important

[19] We intentionally remain vague about the exact characterization of this causal force. It has been characterized alternately as an incorporeal agency, substance, energy, special property, or "force" in the sense of gravitational or electromagnetic forces (Inagaki & Hatano, 1993; Toulmin & Goodfield, 1962). All of these possibilities constitute vitalistic theories.

"life stuff" around between various working body parts (cf. Crider, 1981), even if children don't yet know the specifics of what that stuff consists of and how the body parts "work". This notion would be equally consistent with simple Vitalistic and Mechanistic explanations for various bodily phenomena -- Mechanistic because it conceives of the body as a physiological machine; and Vitalistic because it includes the idea of "Life stuff" that interacts with this machine.

On this story, then, the shift that happens between 6 and 8 years of age "from a vitalistic to a mechanistic biology" (Inagaki & Hatano, 1993), or from preferring both Vitalistic and Mechanistic explanations to preferring Mechanistic over Vitalistic explanations (in the current study) simply consists of the further specification of the physiological mechanisms as the child learns more specific information about the human body. It remains an open question when, or whether, children ever reject the notion of this vitalistic "life stuff", and in so doing make the conceptual leap from a vitalistic to a mechanistic theory of biology.

3.5. Appendix -- Practice Story, Question, and Potential Explanations

STORY: Mary and John were climbing a tree. All of a sudden, the branch that John was sitting on broke, and he fell to the ground.

QUESTION: Why did John fall?

POTENTIAL EXPLANATIONS:

causal / true:	Because the branch that John was sitting on broke.
causal / not true:	Because Mary pushed John out of the tree.
non-causal:	Because John has blue eyes.

CHAPTER 4:

Do Plants Play Any Role in Children's Early Biological Theory?

4.1. Introduction

The argument we have been pursuing in this thesis runs as follows. An intuitive theory is composed of the following three components: an ontology, phenomena, and domain-specific causal explanatory principles. In Chapter 1, we noted that there is evidence that by age 4, children have both: (1) a potential biological ontology (i.e., they differentiate animal from non-animal); and (2) a potential set of biological phenomena (i.e., they differentiate physical/physiological from social/psychological phenomena). The problem is that we don't know on what basis children are making these distinctions. The claim in many studies (e.g., Backscheider et al., 1993; Rosengren et al., 1991; Springer, 1992; Springer & Keil, 1989, 1991; Springer & Ruckel, 1992) is that these distinctions provide evidence that young children have a biological theory. The (implicit) assumption behind this claim is that these distinctions are made on the basis of biological criteria. However, this is not the only option. As discussed in Chapter 1, these exact same distinctions could instead be based on either: (a) psychological/sociological criteria; or (b) atheoretical facts that children have learned. If either of these alternatives are true, then these distinctions cannot be taken as evidence that young children have a biological theory.

Up until this point, we have side-stepped the issue of plants altogether, and have focused exclusively on the child's knowledge regarding animals. The reason for this is that in one sense, children's knowledge of plants is irrelevant to the debate. That is, our criteria for crediting a child with an intuitive biological theory simply require that he represent <u>a</u> biological ontology. There is no reason to preclude the possibility that the child could first construct a biological theory which encompasses only the ontological kind *animal*, and which later comes to include plants. In other words, the child's first biological theory does not <u>have to</u> include <u>both</u> animals and plants. Thus, for the purposes of establishing whether and when children possess a biological theory, we can go by the less stringent criterion of an *animal* ontology, and remain non-committal about whether children think plants are also biological entities.

In another sense, however, the status of plants may actually be quite crucial to our story. Suppose, for example, that we knew that young children unite plants and animals (and not inanimate objects) into a single, coherent conceptual category. How would this affect our argument? Most importantly, our claim that the young child's purportedly "biological ontology" could be based on social or psychological criteria would become untenable. Plants, unlike animals, do not easily fall under the umbrella of any social or psychological theory. Thus, if young children understand that plants and animals (and not inanimate objects) are "the same kind of thing", then this would suggest that they are making an ontological distinction on the basis of biological criteria. In other words, it would suggest that they do have some sort of biological theory.

4.1.1. Do children think plants are "biological" entities?

The status of plants in young children's conceptual system has been controversial for over a decade. Carey (1985b) made the claim that young children (before the age of about 10) don't know enough biology to justify putting plants and animals together in the same conceptual category (i.e., "living thing"). This claim was based on the results of two experiments.

Carey's (1985b) first piece of evidence came from a life attribution task, in which she simply asked children whether or not various objects are alive, and why. Among children between the ages of 4 and 7, there were two main patterns of response. Those children who attributed life to animals, but not to plants, also correctly claimed that inanimate objects are not alive. In contrast, those children who judged both animals and plants to be alive also attributed life to some inanimate objects. This result suggests that 4- to 7-year-old children have a clear concept of animals as distinct from non-animals, but that they do not have an inclusive concept of living things (i.e., one including both plants and animals) as distinct from inanimate objects.

Carey's (1985b) second piece of evidence came from a study which examined whether children's projection of a novel property would be constrained by the conceptual category *living* *thing*. In this study, 6-year-old children were taught a novel property (e.g., that X had "golgi") for either two animals, a plant and an animal, or a plant. The children were then asked whether or not each of a series of other entities (both living and non-living) shared this property (e.g., "Do people have golgi?", "Do clouds have golgi?"). Children who were taught the property for an animal and a plant attributed golgi to inanimate objects more than those who were taught the property for two animals or for a plant. These results thus parallel the results from the life attribution task, and suggest that 6-year-old children do not have a unified category of living thing (including both plants and animals) that could constrain their projections.

Potential corroborating evidence for this view also comes from Keil's (1989) transformation studies. In these studies, Keil told children stories about a scientist changing one thing into another by a series of transformations. For example, in one story the scientist took a raccoon, dyed it black and white like a skunk, surgically inserted a sac of smelly stuff into it, and taught it to act like a skunk. The children's task was simply to decide whether in the end it was "really" still the first thing (e.g., a raccoon) or was "really" the second thing (e.g., a skunk). Keil found that the youngest children (age 5): (1) virtually always accepted the transformation if it took place within the category of inanimate objects or of plants; (2) sometimes accepted the transformation if it took place within the category of animal; and (3) virtually never accepted the transformation if it crossed these ontological boundaries (i.e., machine --> animal; animal --> plant; animal --> inanimate). This result clearly shows that the children were making some ontological distinction between animals and non-animals. In addition, it suggests that children of this age treated plants and inanimates as the same kind of thing. Unfortunately, Keil didn't test transformations between plants and inanimate objects, so this apparent similarity can only be taken as suggestive.

To summarize, studies have shown that young children (ages 4 - 7): (1) have a concept of animals distinct from plants and inanimate objects; and (2) for at least some tasks, seem to treat plants and inanimate objects as "the same kind of thing" (e.g., Carey, 1985b; Keil, 1989). These results support the idea that young children do not have a unified *living thing* category consisting of both plants and animals. During the last decade, however, a number of other studies have claimed that young children do treat plants as "biological" entities, as shown by the fact that they understand certain "biological" properties (e.g., growth) with respect to plants.

Inagaki and Hatano (in press), for example, showed children pictures of various animals, plants, and artifacts, and asked the children to pick a second picture depicting what the animal, plant, or artifact would look like after a long time. Children as young as age 4 judged that both plants and animals get bigger with time, but that artifacts tend not to. In a related study, Backscheider et al. (1993) told children that some animals, plants, and inanimates had been damaged, and then asked the children: (a) whether these objects could regrow; and (b) whether a person could fix them. Four-year-old children realized that both animals and plants could regrow while inanimates couldn't. In each of these studies, then, young children demonstrated knowledge that both plants and animals grow/regrow, while inanimate objects do not.

Attribution tasks have also provided evidence for children's "biological" knowledge of plants. Hatano et al. (1993) performed a cross-cultural attribution task, in which they asked children whether various entities possessed a number of specific attributes (e.g., whether they are alive, grow, have bones, feel pain, etc.). Although 6-year-old children tended to underattribute life to plants (58 - 68% correct), they performed much stronger for other properties of living things. Specifically, they knew that plants grow and die/wither[20] (72 - 92% correct). In a similar study, Stavy and Wax (1989) asked 6- to 15-year-old Israeli children various attribution questions regarding "life" and other biological properties (e.g., growth, reproduction, eating, and breathing) for plants, animals, and inanimates. Among the youngest children (ages 6 to 8), only about 30 - 45% judged plants as alive. However, over 80% judged that plants grow. In each of these studies, then, children demonstrated knowledge that plants possess at least one "biological" property (i.e., growth).

In sum, a number of studies have provided evidence that children between the ages of 4

[20] Of course, it is unclear whether children understand that die and wither are synonymous processes. Thus, knowing that an animal "dies" and a plant "withers" may not necessarily be the same as knowing that both plants and animals die.

and 8 know that both plants and animals possess certain "biological" properties, such as growth and regrowth (e.g., Backscheider et al., 1993; Hatano et al., 1993; Inagaki & Hatano, in press; Springer & Keil, 1991; Stavy & Wax, 1989). The conclusion often drawn from these studies is that since children treat plants and animals as the same kind of thing (and different from inanimates) for even a single "biological" property, they therefore have an inclusive conceptual category of living thing, and thus a biological theory.

There is a problem with this logic, however. In order to demonstrate a unified *living thing* category, it is not enough to show that young children know, for example, that plants grow. This is simply a fact about the world which they might have learned (atheoretically). Nor is it enough to show that they know that both plants and animals grow (while dolls and rocks do not). This may also just be a fact which children have learned separately about both plants and animals -- in the same way that one might know, for example, that both grass and emeralds are green. In other words, simply knowing that plants grow and that animals grow (as separate facts) is not necessarily the same thing as having a general category ("living thing") to which both plants and animals belong.

Recently, however, there have also been a couple of studies reporting evidence that children treat animals and plants the same (and different than inanimates) in ways that are not so easily explained by a direct appeal to known facts.

Springer and Keil (1991), for instance, probed children's beliefs about possible mechanisms of color inheritance in different ontological kinds. In this study, they told children about a dog, a flower, and a can which each had a certain color, and then asked the children to choose from a set of possible explanations for how each object had gotten that color. Their results showed that 4- and 5-year-old children expected the can to have gotten its color due to human intervention, while they expected the flower and the dog to have gotten their colors from natural causes. From this, Springer and Keil concluded that children had a conceptual distinction between biological kinds (including both plants and animals) and non-biological kinds, as shown by the different kinds of mechanisms they believed appropriate for color acquisition in these "different domains".

Clearly, the above results are not amenable to explanation in terms of "simple fact" learning in the same way that children's knowledge that "plants grow" is. However, we need not appeal to a theory of biology to explain these results either, for two reasons. First, we should note that although Springer and Keil (1991) describe the relevant distinction in their experiment as *biological versus non-biological*, this is not the only possible description. Since their stimulus items included only a plant, an animal, and an artifact (and notably lacked any non-biological natural kinds), the distinction they found between animal and plant versus artifact could also be described as *natural kind versus artifact kind.* When looked at in these terms, one can describe their results as showing that children of this age know that people make artifacts (and therefore influence their properties) but don't make natural kinds (and therefore don't influence their properties). This knowledge has been demonstrated in other studies as well (Gelman & Kremer, 1991).

Second, although the children in Springer and Keil's (1991) study preferred "natural" causes for both the animal and the plant, it is notable that they did not prefer the same natural cause. Specifically, the most preferred explanation for the dog was the "internal natural" explanation, which appealed to something being passed from mother to baby; whereas the most preferred explanation for the flower was the "external natural" explanation, which appealed to the sun shining and rain falling. Since this latter explanation is based on facts that children know about flowers (i.e., that they need sun and water), then if they were responding on the basis of atheoretical factual knowledge, this is exactly the explanation they should pick. That is, even though Springer and Keil's results cannot be explained by a direct appeal to known facts, they can be explained by a simple association to known facts. Thus, we need not (and therefore should not) invoke any theoretical knowledge on the part of the child in order to explain these results.

A second study which poses a potential problem for the "direct appeal to known facts" explanation of children's plant knowledge is Inagaki and Hatano's (in press) "vitalistic attribution study". In this study, they asked children whether various entities possessed certain "biological" properties (e.g., growing, breathing), but additionally gave some children a "vitalistic, biological context" for the property (e.g., "A person becomes bigger and bigger by taking in energy from food and water. Does X become bigger and bigger?") By age 5, children who were given this context tended to attribute growth, taking in food/water, and (to a lesser degree) getting ill to both animals and plants, but not to inanimate objects. Children who were not given this context made similar attributions, although not as strongly, for growth and taking in food/water, but not for getting ill.

Of course, the basic result that children attributed certain properties to both plants and animals is identical to the attribution results discussed earlier (Hatano et al., 1993; Stavy & Wax, 1989) and, like those, can be explained by a direct appeal to atheoretical facts. The more interesting question is why children increased their attributions of these properties to plants when the vitalistic context was given. Inagaki and Hatano (in press) argue that this is because the vitalistic context "activates" the children's concept of living thing. However, an alternate explanation could be given in terms of association with known facts. In the "growth" example given above, for instance, notice that adding the vitalistic context ("by taking in energy from food and water") in effect makes an association between two properties -- getting bigger and taking in water. If children know, as atheoretical facts, that both of these properties apply to plants, then making an explicit association between these properties should make the child more likely to answer affirmatively when asked about either property on its own.

To summarize, during the past decade, a number of studies have attempted to demonstrate that young children have a unified *living thing* concept (including both animals and plants), as shown by the fact that they either: (a) understand that certain "biological" properties (e.g., growth) apply to plants; or (b) treat animals and plants similarly, and differently than inanimate objects, with respect to some particular property (e.g., color acquisition). However, we have argued that in each case, these results could be explained either by direct appeal to atheoretical facts, or by simple association to these facts. Therefore we cannot attribute a unified *living thing* category to children on the basis of these results. In order to show that plants and animals function as a coherent category in children's conceptual system, we must use a novel piece of information that children could not possibly have learned as an atheoretical fact about the entities involved, and similarly could not "guess" on the basis of simple association to these facts.

4.1.2. The current study

The current study explores whether young children treat plants and animals as a coherent category with respect to new information. To accomplish this, we've adapted the induction paradigm from Carey (1985b). In this paradigm, children are taught a new property for a specific object (e.g., dogs have spleens). They are then asked whether or not each of a series of other entities shares this property (e.g., "Do cats have spleens?", "Do bees have spleens?", "Do rocks have spleens?"). In the current task, children are also asked to project new characteristics, but with a twist. The twist is that they are taught the new characteristic as an explanation (i.e., mechanism label) for a potentially biologically relevant property, which is nevertheless superficially shared by all of the items involved. For example, lions, flowers, and balloons all get bigger, but clearly not all for the same reasons. In this study, a child might be told that "Lions get bigger because of zarches." The question is how far children will then project this mechanism for getting bigger. If children's knowledge that plants and animals get bigger is based on their knowledge that plants and animals belong to the same conceptual category of living things, and that "living things grow", then we would expect children's projections to pattern in such a way that animals and plants are grouped together, and separate from non-living things. On the other hand, if children's knowledge that plants and animals get bigger is based on knowing that plants get bigger and that animals get bigger (as separate facts), then we would expect children to either constrain their projections such that animals and plants pattern separately (suggesting different mechanisms), or to project the mechanism to all entities (suggesting their projections are based on a simple association to the property of "getting bigger").

4.2. Method

4.2.1. Subjects

One-hundred eight children participated in this study: thirty-six 6-year-olds (range 6;1 - 6;11; mean = 6;6), thirty-six 8-year-olds (range 8;1 - 9;0; mean = 8;7), and thirty-six 10-year-olds (range 10;0 - 11;0; mean = 10;6). There were an approximately equal number of boys and girls in each age group. At each age, the children were randomly assigned to three training groups of twelve children each. Each group was trained on either animals, plants, or non-living things. Children were tested individually in a private room at their school.

4.2.2. Materials

Two stimulus sets were created -- one each for two different properties: getting bigger and taking in water. For each property, the stimulus set consisted of three animals, three plants, and three things which posses that property (see Table 4.1 for stimulus list). The stimuli were presented as line drawings on laminated white cards (3-1/2" x 3-1/2") arranged in a 3 x 3 matrix. An additional card for the training item was presented to the side of the stimulus matrix. This training item was identical to one of the stimulus items.

Table 4.1. Stimulus items

	GET BIGGER	TAKE IN WATER
ANIMALS	Lion	Bear
	Chicken	Duck
	Fish	Snake
PLANTS	Flower 1	Flower 2
	Tree 1	Tree 2
	Bush 1	Bush 2
THINGS	Balloon	Sponge
	Fire	Eye dropper
	Tire	Towel

Two nonsense words (*blickets* and *zarches*) were created to be used as the mechanism labels for the two properties. For the sake of the experimenter's sanity, each mechanism-label always accompanied the same property (i.e., get bigger mechanism = "zarches"; take in water mechanism = "blickets").

4.2.3. Counterbalancing

The following factors were counterbalanced across children in each age and training group: question order, stimulus order, and taught-on item.

Question order: Half of the children in each age/training group received the "get bigger" question first, and half received the "take-in water" question first.

Stimulus order: Each stimulus set was presented in two quasi-random orders, with the constraint that no more than two objects from the same category (i.e., plants, animals, things) could appear successively. Half of the children in each age/training group received the stimuli in one order, and half in the other order.

Taught-on item: For each question, one-third of the children in each age/training group were trained on each stimulus item from that category. For example, in the "trained-on animals" group for the "get bigger" question, four children at each age were trained on lion, four on chicken, and four on fish.

4.2.4. Procedure

After establishing rapport, the experimenter told the children that she was interested in discovering what children knew and thought about science. She then told them that she was going to ask them "all kinds of questions" about science. She further explained that if they didn't know the answer to any of the questions, they could guess.

Each child received two trials -- one for each property. Each trial proceeded in the following manner. First, the experimenter laid out the stimulus set in a 3 x 3 matrix and presented the relevant property (e.g., *Here are some pictures of things that get bigger.*). Second, the experimenter went through the stimuli individually, pointing to each item and reiterating that the property applies to that item (e.g., *Lions get bigger; flowers get bigger;* etc.). This had the purpose of both ensuring that the child knew what each picture represented, and emphasizing that the property applied to all of the stimulus items. Third, the experimenter presented the training item to the side of the stimulus matrix and supplied the child with the relevant mechanism label (e.g., *Sometimes different kinds of things get bigger for different reasons. For example, lions get bigger because of zarches. Can you say zarches? Zarches make lions get bigger. If lions didn't have zarches, they wouldn't get bigger.*). Finally, the experimenter asked the child to perform an induction for each stimulus item (e.g., *What about flowers? Do you think flowers have zarches*?).

Children were given as much time as they needed to answer each question, and if they were silent or said they didn't know, they were asked to guess. Regardless of their answers, children were always provided with positive encouragement, and told that they were doing well. The entire testing procedure took approximately 5 - 10 minutes for each child.

4.3. Results

The basic question we're concerned with is how far children will project the mechanism for each property. We can envision several possible outcomes. First, children might not project the mechanism at all, restricting it only to the particular item on which they were taught. Second, children might project the mechanism only to the particular category of items on which they were taught (i.e., plants, animals, or things). Third, children might project the mechanism to a conjoined set consisting of two of the three categories (e.g., plants and things; plants and animals). Finally, children's inductions might be driven purely by whether the entity possesses the property associated with the taught trait (e.g., growth = zarches). In that case, we would expect children to project the property to all three classes of entities.

Notice that it is the third pattern of projections (i.e., conjoined category) which provides us with the most useful information regarding the status of plants in children's conceptual system. For example, suppose that children project the mechanism to plants and animals, but not to things. This would suggest that young children view plants and animals as the same kind of entity, and different from things -- which would support the idea that children have an integrated category of living thing (and thus a biological theory). Alternatively, suppose that children project the mechanism to plants and things, but not to animals. This would suggest that children think that plants and things are in some sense the same kind of entity, and different from animals -- which would support the idea that children do not have an integrated, biological category of living thing consisting of both plants and animals. The majority of our analyses thus focus specifically on children's projections to conjoined categories.

The results will be presented in three sections. First we will examine the general patterns of projections children made in each of the different training conditions. Second, we will examine evidence for children's possession of a conjoined animal-plant category at each age. Finally, we will examine children's individual patterns of responding in order to explore the stability of this conjoined animal-plant category in children's inductive generalizations.

4.3.1. Projection Patterns

Strict coding. Children's patterns of responses were first coded with respect to the possible projection patterns outlined above, according to the strict criterion of perfect responding for each pattern. Specifically, the coding categories were as follows:

(1) *Target* -- yes to trained-on item; no to all other items

(2) *Within category* -- yes to all three items from within the training category; no to all six items in the other categories (e.g., if trained on bear: yes to all animals; no to all plants and things)

(3) *Conjoined category* -- yes to all six items in two categories; no to all three items in the other category. There were three specific possibilities here:

(a) *Animals and Plants* [AP]

(b) *Plants and Things* [PT]

(c) *Animals and Things* [AT]

(4) *All* -- yes to all nine items

(5) *Miscellaneous* -- any other pattern of responses

Table 4.2 shows the number of response patterns falling into these different categories for each age and training category. Note that each column represents 24 responses (12 children x 2 responses per child). The probability of responding according to any of the projection patterns (save miscellaneous) was less than .002. Thus, any non-miscellaneous responses at all were more than would be expected by chance alone ($p < .01$).

Table 4.2 Number of responses in each coding category (strict coding)

	PLANTS			ANIMALS			THINGS		
	Six	Eight	Ten	Six	Eight	Ten	Six	Eight	Ten
target	4	2	0	5	3	3	12	6	0
all	2	3	0	2	2	2	2	0	3
w/in	8	8	14	2	6	5	0	1	0
AP	0	0	5	1	4	6	---	---	---
AT	---	---	---	0	0	0	0	0	0
PT	0	0	0	---	---	---	0	0	2
msc	10	11	5	14	9	8	10	17	19

From examining the table, we can clearly see that children's projection patterns differed dramatically as a function of training category. When trained on plants, at least one-third of the responses at all ages (over one-half in the case of 10-year-olds) projected the property to all and only plants. When trained on animals, the patterns are a bit less uniform. Of the non-miscellaneous patterns, the youngest children seemed to favor restricting the property to the target item, while the older children projected the property either to animals, or to both animals and plants. Finally, when trained on things, we see a clear age progression in which the youngest children preferred to restrict the property to the target item, while the older children were much more willing to project the property, but not to any clearly-defined category.

With respect to conjoined categories, several results are of interest. First, we see clear evidence of a conjoined animal-plant category. This seems to be most prevalent in the case of 10-year-olds, and more evident when children were trained on animals than when they were trained on plants. There is very little evidence at any age of a conjoined plant-thing category, and no evidence (thankfully) of a conjoined animal-thing category.

Given the large number of miscellaneous patterns in all age and training groups, however, it is possible that this first coding scheme was simply too strict to capture all of the relevant patterns. Therefore, we next coded children's responses according to a looser generalization criterion.

Loose coding. In this second coding pass, children's patterns of responses were coded according to the looser criterion that they could make one mistake in the projection pattern. Specifically, the "loose" coding categories were as follows:

(1) *Target* -- yes to trained-on item; no to all other items [same as in strict coding]

(2) *Within category* -- three possibilities:

(i) yes to all three items from within the training category; no to all six items in the other categories;

(ii) yes to two of the three items from within the training category; no to all six items in the other categories;

(iii) yes to all three items from within the training category; no to five of the six items in the other categories;

(3) *Conjoined category* [AP; PT; or AT] -- three possibilities:

(i) yes to all six items in two categories; no to all three items in the other category:

(ii) yes to five of the six items in two categories; no to all three items in the other category:

(iii) yes to all six items in two categories; no to two of the three items in the other category:

(4) *All* -- two possibilities:

(i) yes to all nine items

(ii) yes to eight of the nine items

(5) *Miscellaneous* -- any other pattern of responses

Table 4.3 shows the number of response patterns falling into these different categories for each age and training category. As before, each column represents 24 responses (12 children x 2 responses per child). The probability of responding according to any of the loose projection patterns (save target and miscellaneous) was less than .02. Thus, any more than 1 response in any of these categories represents greater than chance responding ($p < .05$).[21]

Table 4.3 Number of responses in each coding category (loose coding)

	PLANTS			ANIMALS			THINGS		
	Six	Eight	Ten	Six	Eight	Ten	Six	Eight	Ten
target	4	2	0	5	3	3	12	6	0
all	4	6	1	4	2	4	6	0	9
w/in	12	11	16	8	10	6	0	7	5
AP	2	1	5	3	5	10	---	---	1
AT	---	---	---	0	0	0	0	1	2
PT	0	1	0	---	---	---	1	2	2
msc	2	3	2	4	4	1	5	8	5

The most obvious (and expected) result of this looser coding is that the number of miscellaneous patterns are reduced sharply in all age and training groups. Besides this rather broad result, for those children trained on plants or animals there was not much qualitative change in the patterns of responses. When trained on plants, children tended to project the mechanism to plants. When trained on animals, children tended to project the mechanism to animals or to both animals and plants. (It is interesting to note that there seems to be a switch in this preference between the ages of 8 and 10.) Finally, when trained on thing, the youngest children either restricted the property to the target item or projected it across all categories, while the oldest children preferred to project it across all categories, or to just the category of things.

With respect to conjoined categories, we again see evidence for a conjoined animal-plant category, which seems most evident among 10-year-olds and for those children trained on animals. In addition, we also see a bit more evidence of conjoined plant-thing category for a couple of children. However, this remains at very low levels across all age groups.

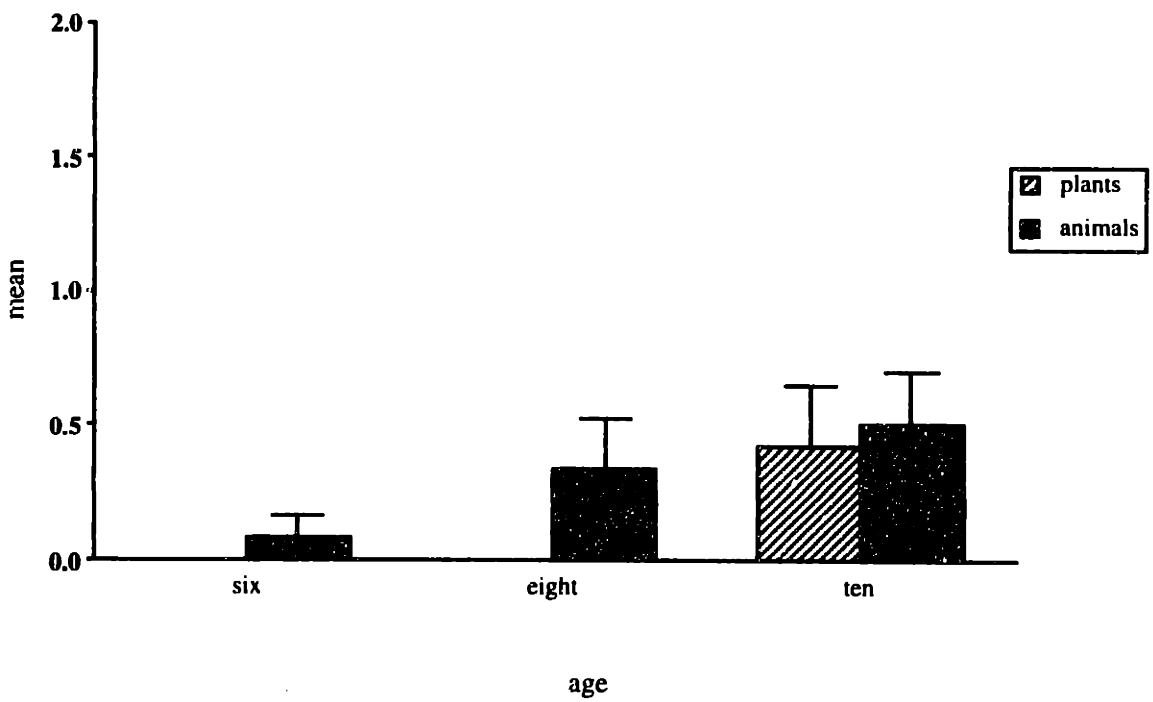
[21] As before, any responses at all falling into the target-only pattern represent greater than chance levels ($p < .01$).

4.3.2. Conjoined Animal-Plant Category

Because our fundamental interest is in determining whether and when children treat animals and plants as belonging to a single, coherent category, the rest of our analyses focus specifically on evidence for a conjoined animal-plant category. Because we could only meaningfully expect a generalization pattern to plants and animals (and excluding things) from children who were trained on either plants or animals, children who were trained on things were excluded from these analyses.

Again, we began with the strict coding categories (i.e., requiring perfect responding). Children were given a score of 1 for each trial on which they projected the mechanism to all animals and plants, but to no things (i.e., the AP-strict coding category) -- resulting in a score between 0 and 2 for each child. Figure 4.1 shows the mean number of AP-strict projection patterns found in each and training group.

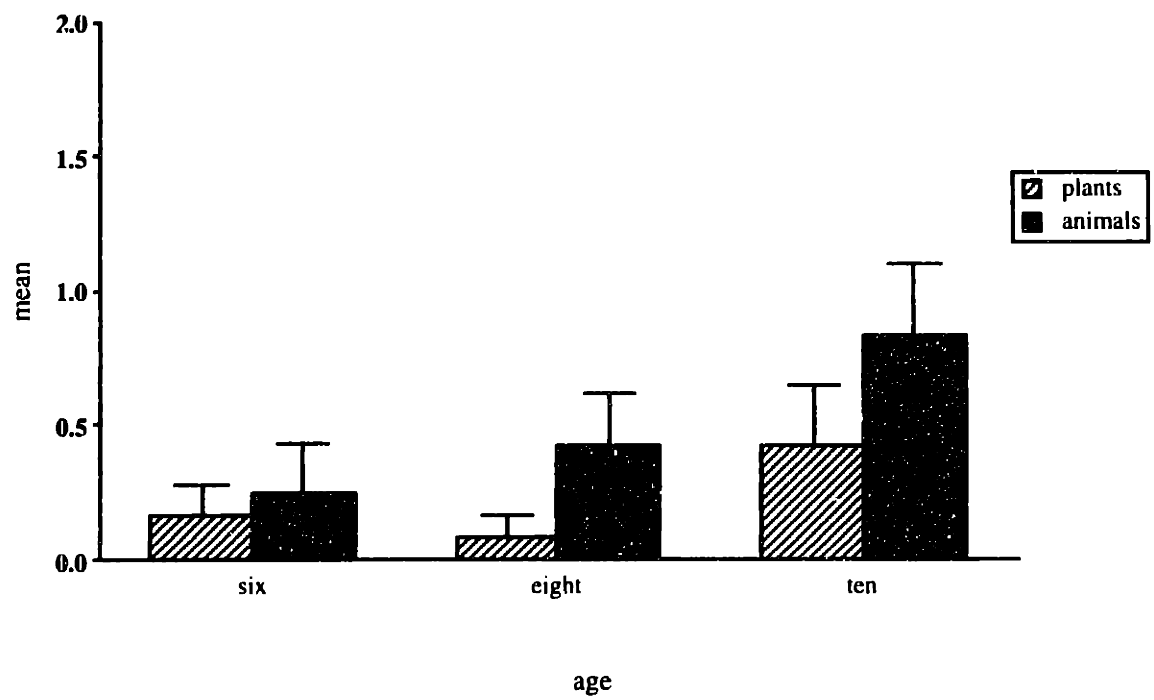
Figure 4.1. Mean number of AP patterns (strict coding)



A 3 (age) x 2 (training group) Analysis of Variance was performed on these data. There was a main effect of age, $F(2, 66) = 4.14, p < .03$. Specifically, 10-year-olds had more AP patterns than 6-year-olds (Fisher, $p < .05$); 8-year-olds were not significantly different than either 6- or 10-year-olds. There was no main effect of training group ($p > .17$), and no significant interaction between age and training group ($p > .62$). Thus, we see growing evidence of a conjoined animal-plant category between the ages of 6 and 10. Specifically, evidence of this AP category is virtually nonexistent in 6-year-olds and increases to almost 25% of responses by age 10.

As before, however, it is possible that our strict coding categories are so strict as to obscure interesting and relevant data patterns. Thus, we next performed a similar analysis using the loose coding categories (i.e., in which children could make one mistake in the projection pattern). Children were given a score of 1 for each trial on which their projection pattern adhered to the AP-loose coding category -- resulting in a score between 0 and 2 for each child. Figure 4.2 shows the mean number of AP-loose projection patterns found in each and training group.

Figure 4.2. Mean number of AP patterns (loose coding)



A 3 (age) x 2 (training group) Analysis of Variance was performed on these data. There was a marginal effect of age, $F(2, 66) = 2.94, p < .06$. Specifically, 10-year-olds had more AP patterns than 6-year-olds (Fisher, $p < .05$); 8-year-olds were not significantly different than either 6- or 10-year-olds. There was also a marginal effect of training group, $F(2, 66) = 3.24, p < .08$, such that children trained on animal had more AP patterns than children trained on plant. There was no significant interaction between age and training group ($p > .65$). Thus, we seem to be seeing two patterns. First, as with the strict coding, there is growing evidence of a conjoined AP category between the ages of 6 and 10. Second, children seem more willing to project the mechanism from animals to plants than from plants to animals.

4.3.3. Individual patterns

For our final set of analyses, we turn to the question of the stability of AP responding in the generalization patterns of individual children. At issue in this analysis is when children begin to show a stable *living thing* category that actively structures their inductive generalizations. Specifically, we counted a child as showing this stable pattern if they responded in accordance with an AP category on both trials. As in the previous set of analyses, only children who were trained on either plants or animals were included.

In our first individual analysis, we counted a child as possessing a conjoined plant-animal category only if she projected the mechanism to all animals and plants, but to no things (i.e., the AP-strict coding category) on both trials. Table 4.4 shows the number of children at each age classified as having a conjoined animal-plant concept [AP] versus children who were not [non]. A chi-square performed on these data showed no significant differences between ages ($p > .15$). From the table, it is clear that very few children showed this pattern at any age. Not a single 6-year-old was classified as having an AP category, and even among the 10-year-olds, less than 15% of the children showed this pattern.[22]

[22] Of course, it should be noted that any children responding according to this criterion would be more than would be expected by chance ($p < .001$). Thus, any individual child who shows this pattern can safely be assumed to have the conceptual category of living thing.

Table 4.4 Number of individual children classified as AP vs. non according to strict coding

	six	eight	ten
AP	0	1	3
non	24	23	21

Admittedly, however, this requirement of showing an AP-strict pattern for both trials may set the hurdle a bit high. Thus, we next performed a similar analysis using the loose coding categories (i.e., in which children could make one mistake in the projection pattern). A child was counted as possessing a stable conjoined plant-animal category if his projection pattern fell into this coding category (AP-loose) on both trials. Table 4.5 shows the number of children at each age classified as having a conjoined animal-plant concept [AP] versus children who did not [non].

Table 4.5 Number of individual children classified as AP vs. non according to loose coding

	six	eight	ten
AP	1	1	6
non	23	23	18

A chi-square performed on these data showed a significant difference between ages, χ^2 (2) = 7.03, $p < .03$. Specifically, the 10-year-olds were significantly different from both the 6-year-olds, χ^2 (1) = 4.18, $p < .05$, and the 8-year-olds, χ^2 (1) = 4.18, $p < .05$, while the 6-year-olds and the 8-year-olds were not different from each other. Even with this loose coding criterion, only a single child at ages 6 and 8 exhibited a stable AP category. At age 10, in contrast, one-quarter of the children did so. Thus, it seems clear that while a small number of individual children may show this pattern at younger ages, this conjoined AP category (i.e., *living thing*) does not generally begin to play a stable, active role in children's conceptual system until approximately 10 years of age.

4.4. Discussion

The major concern of this study was to examine when children begin to show evidence of a unified living thing concept (i.e., one that includes both plants and animals). Previous research had shown that by age 4, children apply at least one "biological" property to both plants and animals (i.e., growth). From this, it was argued that they had a biological category which united plants and animals under a single concept (e.g., Backscheider et al., 1993; Inagaki & Hatano, in press; Springer & Keil, 1991). As we pointed out earlier, however, this reasoning is flawed. Knowing that both plants and animals grow can simply be the result of learning this (potentially atheoretical) fact about both plants and animals. This same argument can also be made for any other factual information that children might know (e.g., plants need water; plants wither, etc.), and also for any information that children could guess or reason about by simple association to these facts (e.g., that plants get their color from the sun and the rain [Springer & Keil, 1991]). Consequently, in order to show evidence for a unified living thing category, it is necessary to use a novel piece of information that children could not possibly have learned, and could not simply associate to known facts.

In the current study, therefore, we presented children with a novel piece of information about either a plant, an animal, or a non-living thing. This information was presented as the mechanism responsible for a potentially biologically relevant property (e.g., getting bigger or taking in water). The question was to which other entities children would project this mechanism, and specifically at what point their projections would show evidence of being governed by a unified concept of living thing. In contrast to previous studies, we specifically chose our non-living thing exemplars to control for responses by simple association to atheoretical facts. That is, since the non-living things in this study also shared the surface property in question (i.e., getting bigger or taking in water), a response strategy based on simple association would have resulted in projections to all stimulus items, rather than to just animals and plants.

There were several results worth noting. First, the task seemed to be meaningful to the children (i.e., they weren't merely guessing), as judged by the fact that the majority of their responses fell into one of several highly unlikely, meaningful patterns. Second, although there was some evidence that individual children at ages 6 and 8 had a unified living thing category, these patterns were rare, and did not seem to play a prevalent role in structuring children's inductive generalizations until 10 years of age. Finally, by at least age 6, children seemed to have a clear concept of *plants* as a coherent category. Moreover, there was very little evidence that children ever had a unified plant-thing category. This suggests that before children unite plants and animals into a coherent living thing concept, they presumably view plants and animals separate, ontologically distinct types of entities.[23]

There is an obvious potential objection to this study, however, which runs as follows. Our conclusions about the late arrival of children's unified living thing category come from the finding that before age 10, children rarely projected the novel mechanism to both animals and plants while excluding things. However, just because children did not use an animal-plant category to constrain their inductive projections does not necessarily mean that they could not use it. That is, even with a conjoined animal-plant category, it is perfectly reasonable to assume that there will be some characteristics that apply to animals but not to plants (e.g., blood), and some that apply to plants but not to animals (e.g., chlorophyll). Thus, children might reasonably "under-extend" the mechanism to only plants or only animals. Conversely, even with a conjoined animal-plant category, it is also perfectly reasonable to assume that there will be some characteristics that apply to all animals, plants, and non-living things (e.g., molecules). Thus, children might reasonably "over-extend" the mechanism to all entities. Therefore, since there are several reasonable strategies children might have used, the fact that they didn't use the single strategy we had in mind is not necessarily indicative of their lack of the concept.

Our response to the above criticism comes in two parts. First, we must acknowledge that there is truth to the above argument. That is, lack of evidence for a concept is not the same thing as

[23] There was no evidence in the current study that children of this age have an analogous concept of *thing* consisting of all entities that are non-plants and non-animals.

evidence against it. However, it is important to keep in mind what the issue is. The current study was simply meant to address the claim in the literature that young children have a unified living thing category. Clearly, evidence that children know a fact about plants and animals is not sufficient to support this claim. To support this claim, you would need something like the task performed here, in which children must make a novel generalization. In this particular study, we chose our properties -- getting bigger and taking in water -- precisely because these are the properties from which the argument has been made that children have a "biological" understanding of plants (e.g., Backscheider et al., 1993; Hatano et al., 1993; Inagaki & Hatano, in press; Stavy & Wax, 1989). However, the difference between our study and previous studies was that in our study, children had to make a novel inference regarding these properties, and this inference could not be carried by association to known facts. Specifically, they had to infer whether the mechanism responsible for these properties was the same for plants, animals, and non-living things (which all shared the property in question). Our results suggested that young children did not make this inference according to a unified living thing category. Anyone who would like to claim a unified living thing category for young children would need to demonstrate that children can show positive evidence of such a category on a task like this (even if they don't show it in this one).

As a second response, we should point out that we did find evidence of a clear developmental trend in which a unified living thing category became more prevalent in children's reasoning between the ages of 6 and 10. This is something which must be explained. An explanation consistent with the above criticism would run as follows: Children have a unified living thing concept even at age 6. At this age, however, they don't use this concept in this task, whereas at age 10, they do. We would then still need an account of what was changing between the ages of 6 and 10 to cause this shift in task strategy. The alternative explanation (and the one that we currently favor) is that most children at age 6 do not have a unified living thing category, and therefore their projections are not constrained by it. The change that we see between ages 6 and 10 is largely a reflection of the fact that by age 10, more children possess this unified living thing concept.

This brings us to the question of how children's knowledge of plants might inform our notions of the development of their early biological understanding. According to the data presented in Chapters 2 and 3, children show a dramatic shift in reasoning about bodily functions and processes between 4 and 6 years of age. Our claim is that this shift is indicative of the construction of their first biological theory. A priori, there were three possibilities for when children may have shown knowledge that plants and animals belong to the same conceptual category: (1) before this shift; (2) at the same time as this shift; or (3) after this shift. If children showed this knowledge before the shift, we would be forced to revise our thinking and credit them with a biological theory at an earlier age than we had supposed. If at the same time, then this would suggest that children's first biological theory is constructed with an ontology consisting of both plants and animals. If after, this would suggest that children's first biology is constructed with an ontology consisting of only animals, to which plants are added later. Based on the results of the current study, this third alternative seems the most plausible. Therefore, we would argue that children construct their first biological theory at around age 6, using an animal ontology. Plants are added to this ontology later, perhaps at about age 10.

Finally, it is worth pointing out that our results are consistent with Carey's (1985b) claim that before the age of about 10, children don't know enough biology to justify putting plants and animals together in the same conceptual category (i.e., *living thing*). However, whereas she interpreted this as evidence that children before this age do not have an autonomous biological theory, we interpret it as evidence that children before this age do not include plants in their early biological theory.

CHAPTER 5:
Summary and Discussion

5.1 The Debate

During the last decade, there has been a growing debate among developmental cognitive scientists regarding the nature of children's early understanding of biology. This debate began with Carey's (1985b) claim that before approximately age 10, children's understanding of (what for adults are) biological phenomena does not belong to any biological theory, but is instead conflated with the same theory by which they understand psychological phenomena. In other words, Carey claimed, young children don't understand biological phenomena as "biological" at all, but rather <u>mis</u>understand them as "psychological", and thus have an undifferentiated psychology/biology theory.

The critics of this view were numerous and quick to respond. Repeatedly, it was argued that children possessed "biological" knowledge at much younger ages than Carey (1985b) had supposed. First of all, they claimed, by at least age 4 or 5, children distinguish between "biological" and "non-biological" kinds. They know, for example: (1) that animals and plants grow and regrow, while inanimate objects do not (Backscheider et al., 1993; Rosengren et al., 1991); (2) that the mechanisms by which entities get their color are different for animals and inanimate objects (Springer & Keil, 1991); and (3) that while one kind of an inanimate object can be transformed into another kind of inanimate object if you change the parts, an inanimate object cannot be transformed into an animal (or vice-versa) in an analogous manner (Keil, 1989).

Moreover, the critics argued, young children by at least age 4 or 5 are also adept at distinguishing between "biological" versus "non-biological" properties. They know, for example: (1) that stable physical properties are likely shared between a mother and her child, while social or behavioral properties are more likely shared between the mother and her friend (Springer, 1992); (2) that properties with physiological functional consequences are likely to be inherited, while properties with social or psychological functional consequences are not (Springer & Keil, 1989);

(3) that illness is likely caused by medical rather than social or moral factors (Siegal, 1988; Springer & Ruckel, 1992); and (4) that physiological symptoms are more likely contagious than behavioral symptoms (Keil, 1992, 1994).

Since these studies purportedly demonstrated that young children have a lot of previously unrecognized knowledge about "biological" things, and in particular knowledge that separates "biological" from psychological entities and phenomena, it was argued that surely they must have a theory of biology differentiated from that of psychology by at least preschool-age, if not earlier (e.g., Keil, 1992, 1994; Wellman & Gelman, 1992). Carey and her colleagues, however, remained insistent that the knowledge of preschool-age children does not constitute an autonomous theory of biology (e.g., Carey, 1995; Solomon, Johnson, Zaitchik, & Carey, 1996). How can this be?

5.2 The Argument

The most critical thing to realize about the above distinctions is that there is an inherent fallacy in describing them as "biological" versus "non-biological". Specifically, this could be a theory-laden attribution (Carey, 1995). For example, in the adult conceptual system, the distinction between animals and inanimate objects can correctly be described as a distinction between biological and non-biological entities. This is because adults have a concept of what it means for something to be "biological", to which animals belong. But it is not at all clear that we can say the same thing of children. That is, it is not obvious that the 4-year-old's *animal versus non-animal* is the same as *biological versus non-biological* for the simple reason that we don't know whether the 4-year-old's concept of animal is a biological concept.

Admittedly, the previous studies succeeded in demonstrating that children are able to make distinctions between animals and inanimate objects, and also between physical/physiological versus social/psychological phenomena. What they failed to do, however, is to tell us anything about the basis on which children make these distinctions. Simply put, it is possible that children are making distinctions in the world which are co-extensive with the distinctions we (as adults) would make on the basis of our biological theory (e.g., animal versus inanimate object; mental processes versus physiological processes) without any reference to biological criteria at all. There are at least two alternative ways these distinctions could be made. First, given that by age 4, children know a lot about both the psychological and social worlds (Wellman, 1990; Wellman & Gelman, 1992), it is possible that they are making these distinctions on the basis of socially or psychologically relevant versus not socially or psychologically relevant, rather than on the basis of biological versus social/psychological, per se. Second, at least some of these distinctions could be made on the basis of theory-neutral facts and domain-general concept-formation abilities. (For example, children may have constructed a category of plant on the basis of some similarity metric, and may have learned that "plants get bigger" as a simple [unexplained] fact about the world.) In neither of these cases would it be correct to call these distinctions "biological". In order to claim that the child is making distinctions on biological grounds (i.e., that she has a biological theory), we must require that the child uses biological explanatory principles to reason about the phenomena in the domain. The real issue in this debate, then, is whether children know any biological causal principles.

During the past several years, three proposals for biologically specific causal principles have been put forth in the literature: (1) Essentialism (Atran, 1990), (2) Teleology (Keil, 1992, 1994) with biological goals (Carey, 1995), and (3) Vitalism (Inagaki & Hatano, 1993). In the first three chapters of this thesis, we addressed each of these three candidate principles in turn.

In Chapter 1, we reviewed several kinds of evidence for essentialistic reasoning in children. However, we found each case to be deficient as evidence for biologically-specific essentialistic reasoning. Depending on the task, young children (ages 2-1/2 to 5) seemed to: (a) treat all categories essentialistically (Gelman & Coley, 1990; Gelman & Markman, 1986, 1987); (b) treat all categories non-essentialistically (Keil, 1989); or treat some essentialistically and some non-essentialistically, but not according to any potentially biological distinction (Gelman & Wellman, 1991). Older children (age 9) seemed to possess a type of principled essentialistic distinction between different categories, but this distinction seemed to map onto the division between natural kind versus artifact kind, and was thus also not biology-specific (Keil, 1989). Due to this lack of domain-specificity, we concluded that essentialism does not fulfill our criteria for an explanatory principle around which young children's theory of biology might be built.

Chapter 2 described an empirical study addressing the possibility of teleology as a potential biological principle in children's reasoning. In this study, children were interviewed about their knowledge of bodily organs and processes. We found a pervasive shift in children's explanations of internal organ function between the ages of 4 and 6. This shift was not simply reflecting a general increase in factual knowledge about the body, as shown by the fact that it was specific to functional explanations of internal organs, and did not extend to knowledge of either organ location or external organ function. We also found a dramatic shift in children's appeals to the goal of maintaining life at this same age, and presented preliminary evidence that this increase was associated with the changes in children's explanations of internal organ function. Consequently, we proposed that between the ages of 4 and 6, children undergo a significant change in how they reason about the internal workings of the body, and suggested that this shift is driven by their discovery of "Life" as a biological goal for bodily function (i.e., the beginning of biological teleology).

Chapter 3 described an experimental study addressing the possibility of vitalism as a potential biological principle in children's reasoning. In this study, children were asked to judge three different types of potential explanations for various bodily processes -- intentional, vitalistic, and mechanistic. As in Chapter 2, we again found a dramatic change in children's bodily reasoning between the ages of 4 and 6. Specifically, 4-year-olds showed no consistent pattern of preferences among the explanations, whereas 6-year-olds showed a marked preference for both vitalistic and mechanistic explanations. We pointed out that (contrary to our original intentions) our explanation choices in this task did not reliably separate true vitalistic from true mechanistic explanations, and concluded that children's performance could be explained by the emergence of vitalism as a causal reasoning principle between the ages of 4 and 6.

Finally, Chapter 4 presented an experimental study addressing the status of plants in young children's early biological theory. In this study, children were taught a novel mechanism for a "biological" property (e.g., growth) for either a plant, an animal, or a non-living thing (e.g., *zarches* make flowers get bigger). Based on children's patterns of projections of this mechanism to other entities, we found very little evidence of a unified *living thing* category (i.e., one including both plants and animals) before age 10, suggesting that plants are not a part of children's original biological theory.

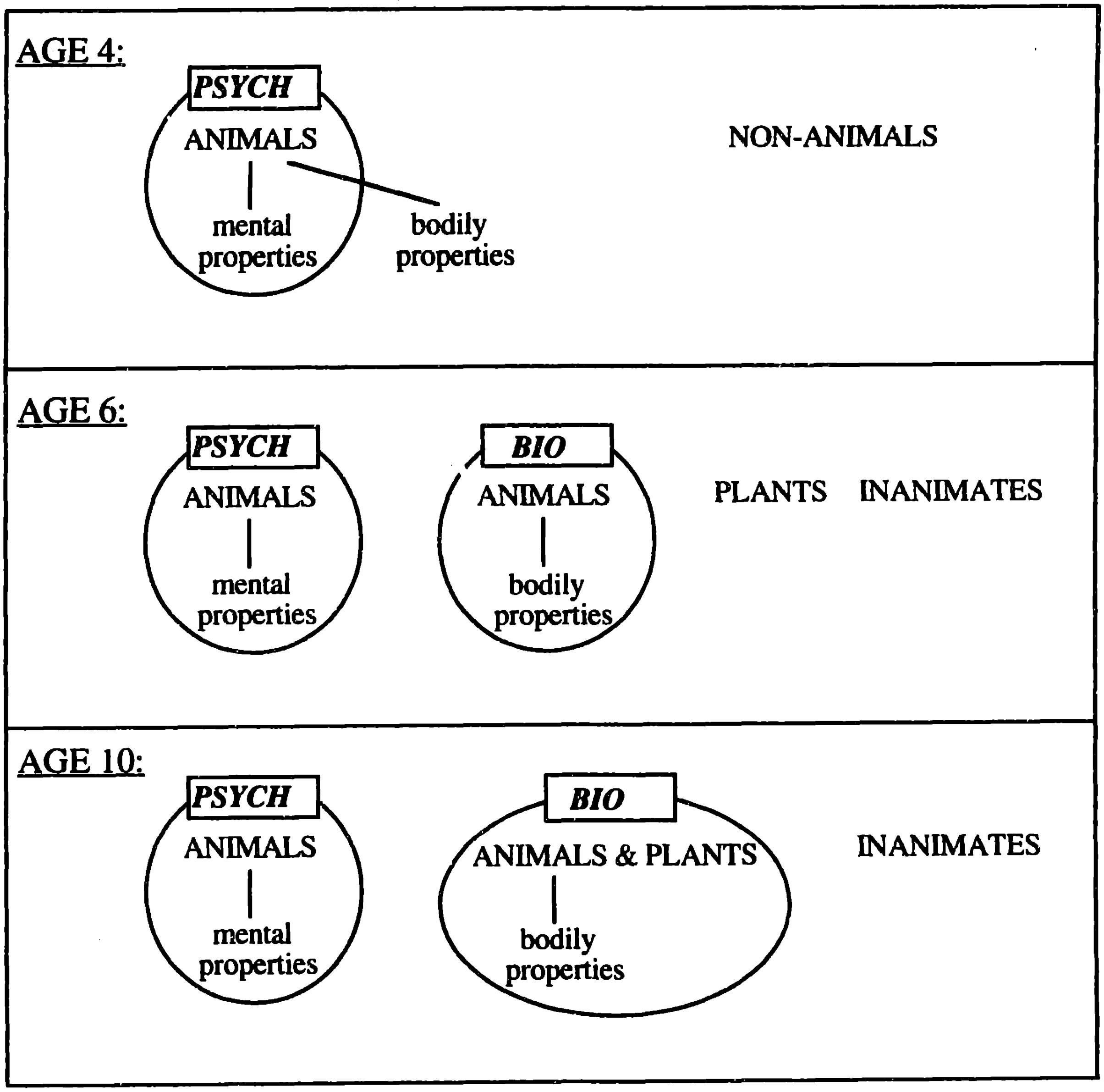
With these data in hand, we are now finally in a position to address the issue of when children possess an autonomous biological theory. First, it seems clear that, contrary to Keil (1992, 1994), preschool-aged children do not possess something that we would consider an autonomous biological theory. With respect to each of the three candidate explanatory reasoning principles, we found that preschool-aged children either simply don't use it, or don't use it to reason about specifically biological things. Second, it also seems clear that, contrary to Carey (1985b), children do possess something that we would consider an autonomous biological theory well before age 10. With respect at least two explanatory reasoning principles (i.e., biological teleology and vitalism), children showed strong signs of using them by 6 years of age. Thus, we are led to the seemingly obvious proposal that children develop an autonomous biological theory somewhere around the age of 6.

5.3 The Story

On the basis of the data presented in this thesis, we have indirectly outlined three stages in the development of children's biological reasoning. These are diagrammed in Figure 5.1.[24] We now attempt a more explicit characterization of these stages and the transitions between them.

[24] This diagram is meant to encompass only those entities and properties dealt with directly in this thesis. For example, although children certainly know that animals also have physical properties, in addition to mental and bodily properties, these are not represented in the figure.

Figure 5.1. Stages in the development of children's intuitive biological theory



On this story, preschool-aged children have an intuitive psychological theory, the domain of which encompasses the mental processes of animals. It is on the basis of this theory that young children are able to segregate animals (psychological) from non-animals (non-psychological), and also bodily (non-psychological) from mental (psychological) phenomena. Children in this stage do not, however, have any theory by which to reason about things which are, for adults, biological phenomena (i.e., bodily processes/properties of animals; plants).[25] Thus, anything they know about these phenomena is either based on domain-general reasoning principles, or may simply exist as unexplained facts.

During the next stage (beginning around the age of 6), children acquire their first true biological theory, the domain of which includes bodily processes/properties of *animals.* It is this shift which was the main focus of this thesis. Several things about this transition still remain to be explained. First, how do children get the "Life"- realization (documented in Chapter 2) which seems to mark the transition from no biology to biology? Second, how is this concept related to the reasoning principle(s) posited to operate as the framework of this theory? And third, according to the evidence presented in Chapters 2 and 3, it appears that both vitalism and biological teleology make their appearance in the child's reasoning about biological phenomena at around the same time. Some analysis of the relationship between these two principles is clearly needed.

To address the first question, we propose (following Carey, 1995) that children's construction of "Life" is co-opted from Gelman's (1990) "innards principle", as follows:

Gelman (1990) argued that a core principle guiding children's identification of, and reasoning about, animals is the *innards principle*. According to this principle, children differentiate entities in the world based on their capacity for self-generated motion, and ascribe to these self-moving entities an internal causal power that is the source of that motion. This category of *animate* entities becomes the core for an *animal* category, which then may become further elaborated on the basis of domain-general learning mechanisms. For example, if a child sees a picture of a cheetah for the first time, he doesn't have to see it move in order to classify it as an animal. Rather, this classification can be made on the basis of shared features with his animal prototype (presumably consisting of things like furry, has legs, has a face, etc.).

During the first few years of life, the child learns a vast amount of factual information about animals -- they move, eat, grow, get sick, die, have babies, etc. However, the only theory they have for dealing with animals -- intuitive psychology -- does not explain many of these facts. The

[25] Note that this is different than the "no autonomous biology" claim of Carey (1985b), in which she proposed that children reason about biological phenomena in terms of a conflated psychology/biology theory.

child thus co-opts the innards principle as an explanation for these other phenomena. Thus, this "something" that is the explanation for movement also becomes the "something" that explains these other bodily properties as well. This "something" is now called *life*.

As the next step in our story, we must tackle the relationship between life, biological teleology, and vitalism. As discussed in Chapter 2, it is clear that teleological/functional reasoning as a mode of construal is not specific to biological reasoning -- at the very least it is present in intuitive psychology, where we explain a person's behavior in terms of his or her goals (usually expressed as "wants" or "desires") (Carey, 1995). Once children construct the idea of *life*, therefore, they simply need to apply this type of reasoning to a new goal -- that of maintaining life. This is now what we have been calling "biological teleology". From there, it is only a very short elaboration to the idea that something must have this goal -- resulting in the idea of a vitalistic force responsible for maintaining life.

Our analysis of this relationship between teleology and vitalism is bolstered by an examination of the idea of vitalism in the Western history of science. Recall that the hallmark of a vitalistic theory is the belief that bodily processes cannot be reduced to purely physical or chemical processes, but that there is some additional causal force which affects the workings of these processes. According to a classic characterization of this force during the vitalism-mechanism debate in Western biology, vitalism is a special kind of teleological force that is found only in living things (Driesch, 1914).[26]

Finally, during the third stage (at approximately age 10), children add plants to their ontology of biological (i.e., "living") things. This transition involves two processes: (1) a recognition of the commonalities between animals and plants; and (2) a conceptual change in the life-concept/innards-principle. By age 6 - 10, children have a category of plants (See Chapter 4) which has presumably been constructed on the basis of domain-general processes of similarity abstraction. They have also learned a vast number of facts about plants, including that they grow,

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[26] Note that Driesch was describing what he believed to be an actual force in the world. In contrast, we are making no claims as to the existence of this force in the real world. Rather, our claim concerns what people believe about the biological world.

need water, die, etc. Children of this age also have a biological concept of animal which is centered on the idea of Life. As discussed above, life is their explanation for animal properties such as growth eating, illness, and so forth. In this third stage, then, children take the concept of life that is their explanation for these phenomena in animals and extend it to explain these phenomena in plants as well -- resulting in a unified living thing category that includes both plants and animals. Presumably the reason this transition takes so long to be realized is that this involves a conceptual change in the meaning of Life, such that it no longer includes the property of self-generated movement as its core.

5.4 Future Directions

Of course, the outline of the developmental story we presented in the previous section was just that -- an outline of a story. As such, there are still a number of issues to be pursued before the story can take its full form. We will suggest just a few.

5.4.1. Conceptual Coherence: Life and other Concepts

In Chapter 2, we presented a brief analysis of the differences between young Life-Theorizers and Non-Life-Theorizers in their knowledge of the body. Given the small number of subjects available for this analysis, we cautioned that the results could only be taken as preliminary and suggestive. An obvious and necessary next step, therefore, is to do a more comprehensive study of the concept of Life and the role it plays in children's knowledge of bodily phenomena. One such study has already shown that Life-Theorizers differ from Non Life-Theorizers in their understanding of death (Slaughter, 1997). Further research is needed to explore specifically how Life-Theorizers and Non-Life-Theorizers differ in their knowledge of bodily function, and also perhaps whether they differ in their knowledge of other biological processes as well (e.g., inheritance; disease).

5.4.2. Training Study: Does Life play a causal role in children's bodily knowledge?

Knowing that Life-Theorizers differ from Non-Life-Theorizers on various measures of bodily knowledge does not necessarily establish that children's realization of Life plays the causal role we have suggested. In order to establish causality, a training study is needed. The study we envision would run something like the following:

Stage 1: Pre-test -- This would consist of a shortened version of the body interview in Chapter 2. From this, Non-Life-Theorists would be selected for training.

Stage 2: Training -- Children would be divided into three training groups, to be trained on either: (1) function only; (2) function + life; or (3) life only. Children in each group would be trained on perhaps two internal organs. For example, the training for "heart" might include:

Function group: *The heart pushes blood all over your body. So if someone didn't have a heart, their blood couldn't move through their body.*

Function + Life group: *The heart pushes blood all over your body. So if someone didn't have a heart, they couldn't live anymore. They would die.*

Life group: *You need your heart so that you can live. So if someone didn't have a heart, they couldn't live anymore. They would die.*

Stage 3: Post-test -- A second body interview.

If Life plays a causal role (and if the training was enough to give them this idea of Life), then we would expect differences between groups not only for the training organs, but for the non-training organs as well. Specifically, the Life groups should not only mention life more often than the non-life group, but (if the results of Chapter 2 are any indication) should also provide more specific bodily functions for internal organs.

5.4.3. Conceptual Change within biology: Are adults still vitalists?

Inagaki and Hatano (1993) claimed that by at least age 6, children have a vitalistic theory of bodily function. The results of this thesis support that claim. Inagaki and Hatano further claimed, however, that by age 8, children move away from a vitalistic theory toward a mechanistic theory of biology. We argue, in contrast, that while children are certainly learning more specific bodily mechanisms during this time period, this is not the same having a mechanistic theory of biology. To qualify as having a mechanistic theory, children would have to abandon the idea of vitalism (i.e., the idea that there is some causal force that is unique to biological entities). In other words, they would have to embrace the idea that bodily processes can be explained in purely physical and chemical terms. This transition clearly involves a monumental change in the meaning of "Life". Although it seems clear that Western biology (as a scientific discipline) made this conceptual change during the past century, it seems less clear to us that lay adults (i.e., non-scientists) have made this shift in their intuitive biological theory (and extremely doubtful that 8-year-old children have).

Our third area of pursuit, therefore, involves asking the question of whether adults (non-scientists) have a vitalistic or mechanistic theory of biology. As a first step, we would perform a pilot test similar to the body interview study, but with the exception that each individual question would be pursued with continual requests for clarification until the person could not elaborate any further. It is at this point (i.e., where explanation "stops") which we would hope to find evidence of whether the person is committed to the idea that life processes are "the same" or "different" from non-life processes. Based on the results of this pilot test, we would hope to be able to design more specific assays for distinguishing between vitalistic and mechanistic theories. We would then use these assays to pursue the question of whether children, or adults, ever make the conceptual leap from a vitalistic to a mechanistic theory of biology.

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