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An abstract to concrete shift in the development of biological thought: the *insides* story

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Abstract

For more than a century, theorists of cognitive development have embraced some form of the thesis that cognitive development proceeds from concrete to abstract knowledge. In contrast to this view, we suggest an abstract to concrete shift in the development of biological thought. In five studies we examine children's expectations for what could be inside animals and machines and we find that children of all ages respond systematically, revealing abstract expectations for how the insides of animals and machines should differ. By 8 years, children seem to have more concrete expectations for the nature of insides, and are substantially more accurate than preschoolers. More broadly, we suspect that an abstract to concrete progression may capture important features of how knowledge develops in the realm of biological thought and in many other areas of understanding as well.

1. Introduction

Many people who spend their lives working with children share a common belief: the younger children are, the more likely they are to think in concrete terms and to have difficulty with abstract aspects of thought. Theorists of cognitive development have similarly embraced such a developmental progression for more than a century. Young children are seen as trapped in the here and now, thinking in terms of vividly remembered instances. Some version of a concrete to abstract shift has been associated with theorists as diverse as Vygotsky, Werner, Piaget, and Bruner, among many others.

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This developmental trend sometimes seems to have an air of inevitability. Where else could a child start learning about the world except from instances? And how else could knowledge of abstract categories develop except from initially considering individuals and then gradually abstracting higher-order regularities? Most accounts of concept formation have adopted the position that initial acquisition must be instance-based. For example, a child coming to understand the superordinate kind vehicle might start with detailed, image-like representations of individual items, and then progress to increasingly abstract representations that embody non-perceptual information. Only through repeated exposure to exemplars of a kind could we form an abstract representation.

In this paper we will examine the concrete/abstract distinction and its consequences in the realm of biological thought. We pick biological thought because it is an area in which many levels of explanation exist in the science and because the nature of the child's earliest explanatory frameworks has been hotly debated. For example, along what dimensions do children expect animals to differ from artifacts? Do children have distinctly biological explanations for phenomena or is their understanding tied to other frameworks centering on psychological, behavioral, or physical principles? What expectations do they have for how animals and machines work? Do they have any understanding of the insides of animals and machines? Before evaluating these questions, we examine the usefulness of the concrete/abstract distinction and its developmental consequences.

2. Abstract and concrete explanations

People seem to know what explanations are when we hear them, although the precise properties of explanations and the characteristics of good versus poor explanations remain controversial. Recent work in the philosophy of science has moved away from the classic Hempel and Oppenheim deductive-nomological model, according to which explanation consists of a set of formal laws and antecedent conditions that are interpreted by logical rules of inference (see Hempel, 1965; Hempel & Oppenheim, 1948). In addition, the idea that notions of causality could be extracted solely from probabilistic information has fallen from favor (Salmon, 1989). Instead, explanation is increasingly seen as having a distinctive character apart from either rules of logical inference or probability. Specifically, notions of function and teleology have become accepted in many domains (e.g., biology). In addition, many researchers have argued that explanations can take the form of mental models of physical properties and processes (Johnson-Laird, 1983) – models with structures that go far beyond systems of deductive logic or probability matrices.

Our sense of concrete versus abstract is illustrated by two distinct approaches to explanation. Mechanistic explanation, typically considered to be concrete, involves notions of causal interaction among various well-specified constituents, usually of a physical nature (Salmon, 1989). For example, a mechanistic account of how a camera works might describe how the light enters the lens, what drives the shutter, and how the film is advanced. Each of these processes can be described in terms of the interaction of constituent parts; such explanations typically involve images of canonical parts and their interactions. Alternatively, a camera might be described by a set of principles that are more remote from any characterization of constituents. For example, an abstract account might describe the functional role of a camera as a recording device for brief temporal slices of reflected light patterns. Cause is central here, but at a more abstract level along an abstract/concrete continuum.

Other descriptions lack the force of causal explanation altogether. Events involving shadows have been described as 'pseudo-causal' because they lack constituent processes that interact in space and time with other processes. As a result, they cannot alter the structure of subsequent processes. No matter how the motions of a shadow are decomposed into sub-events, the parts cannot alter the structure of succeeding events. In contrast, the motions of electromagnetic waves, sold bodies, and biological organisms can all be explained in causal terms because they embody such causal mechanisms (Salmon, 1989).

A different way of understanding the abstract/concrete continuum is to consider the extent to which explanations involving causal mechanisms start to give way to those involving causal powers. To take an example from Harré (1988), "the chemical behavior of large samples of liquids, solids and gases is explained by reference to the behavior of unobservables, molecules and chemical atoms, in the interplay of which chemists find the causal mechanisms of chemical reactions. But one might well ask for an explanation of the behavior of chemical atoms . . . The next level of explanation simply repeats the pattern of the level above" (pp. 141–142). Thus, any explanation in terms of causal mechanisms can be reduced to a lower-level explanation. Harré suggests that "at the end of every explanatory regress we must perforce shift from causal mechanisms to causal powers" (p. 142). Causal powers are the unanalyzable bedrock properties which represent basic dispositions. Harré argues that in everyday life we often lack an understanding of underlying causal mechanisms (or unobservable constituent parts) and thus appeal to causal powers or dispositions – an equally valid, but abstract level of explanation.

The causal powers notion does not equate abstractness with ignorance. Although ignorance of the physical components of a system may preclude a concrete explanation for the system's behavior, it is quite possible to generate a principled, abstract explanation without any knowledge of the physical components. An abstract explanation can work with or without knowledge of concrete components. For example, a computer, considered at an abstract level, is an electronic device that performs complex calculations according to the laws of Boolean logic. This abstract description of a computer allows accurate identification of instances, but does not require knowledge of specific examples of computers or of specific constituent parts. If Turing were somehow transported to the present, he might successfully classify instances of computers despite his minimal knowledge of any of their specific properties or parts. Alternatively, many people today might construct an understanding of computers from their experiences with a set of instances. They use their highly concrete memories of instances to form categories, and they classify new instances according to the perceptual similarity to stored exemplars. In neither case is the explanation of how computers work based on ignorance. One is simply abstract and the other is more concrete.

Research on expert/novice differences provides another example of the distinction between abstract and concrete thought. For example, novice physics students sort word problems on the basis of the physical configuration of the problem; they tend to group together all problems containing an object on a ramp because such problems contain common physical objects and configurations. However, expert physicists tend to sort problems according to the laws of classical mechanics involved (Chi, Feltovich, & Glaser, 1981). In both of these cases, the abstract explanations seem more advanced than explanations based entirely on the physical components. However, as we will argue later in this paper, in many cases of naturalistic learning, abstract explanatory frameworks may also precede concrete instantiations and need not represent a more advanced form of explanation.

Harré's distinction between causal mechanisms and causal powers can be applied to abstract and concrete explanations in the domain of biology. Adults and children who lack training in biology often appeal to causal powers in their explanations of the differences between living and non-living things. For example, unseen internal parts might be held as causally responsible for the surface properties of living kinds, but not for artifacts. Although adults may be able to support such explanations by appealing to unobservable mechanisms, they do so less than trained biologists, just as children do so less than adults. However, even if lay adults and children do not appeal to unobservable generative mechanisms to explain such differences, their accounts can still be explanations. Most researchers of the development of biological thought accept the claim that adults have an autonomous biology. Lay adult explanations are simply less vividly mechanistic than those of trained biologists. Harré's discussion suggests that there is an important difference between not knowing a particular mechanism and not having a systematic way of understanding biological phenomena. Abstract explanatory frameworks are not based in ignorance; they may involve a well-developed and integrative set of causal principles that are not directly dependent on specific, physical, and sometimes unobservable components of the system. For example, one might explain why elements in the same column of the periodic table have similar physical, chemical, and electrical properties in terms of the causal powers of electrons and how they populate the shells around the atomic nucleus. Believing in a set of principles linking electron shells to such things as thermal and electrical conductivity, does not require any clear ideas of real mechanisms that link shell structure to these properties. Similarly one might be fully convinced that something about the atomic structures of oxygen and hydrogen fully explain the phenomenal properties of water, but have no idea of the precise mechanisms involved. A real sense of explanation remains here because other properties of hydrogen and oxygen, such as relative scarcity, might be considered fully irrelevant to an explanation.

From these examples and Harré's discussion of causal powers, abstract explanation can be seen as a broader, rule-based understanding that allows the principled identification of exemplars without reliance on representations of the physical instantiation of the concept. Abstract explanations are typically non-perceptual and non-specific; they do not depend on representations of instances or on component parts. They often take the form of principled beliefs about the nature or operation of the underlying components without requiring specific knowledge of those components. Accordingly, an abstract explanation may serve as a framework that guides the search for concrete particulars and underlying mechanisms. Concrete explanations are typically linked to the physical appearance of specific exemplars, relying on knowledge of the physical, unobservable components. Such explanations are mechanistic and relational in that they can refer to specific interactions of components parts.

3. Abstract to concrete or concrete to abstract

Accounts of the development of explanation typically assume some form of a concrete to abstract shift. According to these models, children's earliest explanations involve simple interactions among obvious physical or perceptual constituents such as simple spatio-temporal contingencies between physical objects. If children lack knowledge of the physical constituents, then they cannot form explanations based on higher-order, abstract, relational information. Conversely, if children possess higher-order explanatory principles, then they must also have knowledge of the nature of the physical constituents underlying the mechanisms.

Although the notion of a concrete to abstract shift seems to capture many intuitions about the course of development, some findings suggest that children's initial concepts may not be instance-bound. For example, Rosch, Mervis, Gray, Johnson, and Boyes-Braem's (1976) pioneering studies of the basic level of organization showed that young children's most salient categories are at an intermediate level of organization, at least for those categories that seem to be hierarchically organized. More recently, Mandler and colleagues (Mandler & Bauer, 1988; Mandler, Bauer, & McDonough 1991; Mandler & McDonough, 1993) have shown that children are often sensitive to considerably more abstract categories for which no straightforward perceptual invariants can be specified. For example, Mandler and McDonough (1993) showed that infants differentiate the global, superordinate domains of animals and vehicles before they have differentiated basic level kinds (e.g., dogs, fish or rabbits). They suggest that processes of perceptual categorization in which infants successfully discriminate categories as similar as horses and zebras may not be typical of infants' concept formation. Infants may form concepts of kinds including perceptually disparate members (e.g., superordinate kinds) before they form concepts of basic level kinds, suggesting that learning models based solely on abstraction from perceptual similarities are insufficient to account for concept acquisition. Knowledge of categories may not always proceed from representations of single instances at the lowest level of abstraction. Instead, relational patterns involving specific functional roles may guide some of the earliest cuts of the world.

Although there is increasing skepticism about whether the development of categorical knowledge follows a simple concrete to abstract shift (Wellman & S.A. Gelman, 1992), that position persists in approaches to the study of development in other areas of cognition, such as causal reasoning (Gentner & Toupin, 1988). Preschoolers might have abstract notions of vehicles and furniture, but their patterns of reasoning about how things work might still be tied to concrete instances. Children's explanations of real-world phenomena may require the use of mental models of perceptually elaborated physical components, not just abstract expectations. Children do seem to be capable of forming mental models of causal phenomena involving simple solids or artifacts (Bullock, 1979; R. Gelman, 1990), but considerable controversy surrounds children's understanding of living things. Some argue that young children lack notions of the mechanisms underlying biological processes and therefore lack an autonomous domain of biological thought (e.g., Carey, 1985; Solomon, Johnson, Zaitchik, & Carey, 1993). Others argue that children entertain highly specific models and exhibit biological thought that is distinct from psychological or physical thought (e.g., Atran, in press; S.A. Gelman & Wellman, 1991; Hirschfeld, 1995; Springer & Keil, 1991). Any model of development based on the assumption of a concrete to abstract shift requires a concrete understanding of biological mechanisms prior to the formation of an abstract biological explanatory framework. Young children must initially have knowledge of the concrete particulars and their simple interactions and gradually acquire higher-order, abstract, relational information; they must shift from attribute based to relational understanding (Gentner & Toupin, 1988).

4. What is the abstract to concrete shift?

Vygotsky is sometimes understood as embracing a concrete to abstract shift in early development and allowing for the opposite in cases of explicit instruction occurring later in life (Vygotsky, 1962). Thus, he envisioned abstract to concrete shifts, but only in pedagogical situations in which a set of abstract principles are stated and then gradually filled in with concrete examples. Curricula in the natural sciences sometimes (although by no means always) take that approach by initially stating a principle, such as the second law of thermodynamics, in abstract formal terms, then providing many concrete examples and mechanistic consequences. This, however, is an overly restrictive interpretation of what an abstract to concrete shift might mean. If our notion of abstract to concrete is not based on pedagogy as suggested by Vygotsky, what sort of change is it? Consider four ways that an abstract to concrete shift might operate:

(A) Even if all knowledge of categories springs from experience with instances (possibly even from a single instance), that experience might immediately yield higher-order abstractions that are more salient than representations of individual exemplars. The representations of instances might be transient and not at all salient. Although this transition could be viewed as concrete to abstract in that experience with a particular instance drives the formation of an abstraction, the important point is that the abstraction is immediately more salient. Thus, the abstract framework becomes dominant in explanations of unobservable properties of that class of instances. If the abstract framework does much of the explanatory work from the start, instances may be used only transiently in discovering that framework.

(B) Children may be born with abstract belief systems without any concrete knowledge. According to this view, children are born with abstract frameworks (e.g., universal grammar) that guide the search for concrete information and underlying mechanisms. For example, current models within the theory of generative grammar posit an abstract, innate framework that guides natural language acquisition. In these models, parameters are set according to concrete experiences with a language. Thus, the concrete details of the language are constrained by a more abstract framework. This is the strongest nativist stance on an abstract to concrete shift.

(C) Children transfer abstract expectations from one domain to another. That is, children's abstract expectations for one domain may lead to similar expectations for another domain, without any concrete knowledge in the new domain. For example, children may have experiences with vehicle motion and may form the abstract expectation that the mechanisms underlying vehicle motion should differ from those underlying animal motion. They need not have concrete experiences of those mechanisms to have abstract expectations for their nature.

(D) Initial representations of instances are global and non-specific. When children first experience a cat, the representation they form is at the level of animal with no additional elaboration. Only later, through additional experiences with cats and other animals is the conceptual framework elaborated to include subordinate classes and individuals. This account of the abstract to concrete shift is perhaps the most appropriate description for the work of Mandler and her colleagues discussed earlier (Mandler & Bauer, 1988; Mandler et al., 1991; Mandler & McDonough, 1993).

In the case of biological thought, development may follow a progression similar to that described in "A" above. However, each of these potential shifts may operate in other domains. In the case of biological thought, children do not lack all concrete knowledge. Nor do they have innate, fully elaborated concepts of animals before they have had experiences with instances. Instead, experience with instances guides the formation of an abstract explanatory framework. However, the abstract framework may be based on experiences with only a few instances and may almost immediately be the driving force behind expectations and explanations.

It is tempting to try to collapse or ally the abstract to concrete shift with other themes that have been proposed in discussions of cognitive development, but such temptations should be resisted. For example, the abstract to concrete shift is distinct from a perceptual to conceptual shift. An abstract to concrete transition does not preclude a more general shift from perceptual to conceptual representations across domains (or even within the domain of biological thought). Perceptual knowledge can be both concrete (i.e., focusing on low-level stimulus characteristics such as edges or perceptual primitives) and abstract (i.e., focusing on higher-order perceptual invariants or relationships). Conceptual knowledge can also be both concrete (e.g., a thought of a particular number) and abstract (e.g., a thought of an arithmetic principle). These two contrasts are often confounded in developmental discussions. Similarly, a holistic to analytic shift (Werner & Kaplan, 1963) does not seem to map easily onto this distinction. Shifting from a focus on global similarity to a few key dimensions or relations does not necessarily involve a shift from concrete to abstract, or from abstract to concrete. Those few central dimensions might be highly concrete and perceptually explicit; they may simply have been difficult to disentangle from other salient dimensions.

Of all the developmental topics that might relate to an abstract to concrete shift, the nativist/empiricist controversy may be the most interesting. The abstract to concrete shift seems to constrain developmental accounts from both nativist and empiricist perspectives, while allowing variants from both. Initially, we thought that the abstract to concrete shift might suggest a nativist perspective. For example, the parameter-setting models of language acquisition mentioned earlier in this paper posit a highly abstract set of ways that grammatical relations might be structured without making any commitments to any of a large number of concrete alternatives (Chomsky, 1980, 1988). Based on different inputs in the target language, the learner might, for example, decide that the language is fundamentally right or left branching and, from that decision, make other decisions about binding relations between elements and clause-embedding relations (Lust, 1994). The details of those relations follow directly from abstract specifications in the initial grammar that state what should happen as a consequence of adopting different parameters (see abstract to concrete shift "B" above). Parameter setting illustrates a case in which a nativist view is consistent with an abstract to concrete shift. In general, nativist accounts that posit an abstract framework that guides the acquisition of concrete structures are consistent with the shift. However, accounts that pre-specify fully articulated, concrete structures are incompatible.

Traditional empiricist accounts in which a learner bootstraps all knowledge from perceptual and sensory primitives, layering higher orders of abstraction upon the perceptual foundation, are also at odds with an abstract to concrete shift. At a minimum, the abstract to concrete shift suggests that lower, concrete layers should not be fully articulated prior to the formation of abstract layers. In addition, the abstract layers should guide the elaboration of the concrete layers. One of the most promising aspects of recent attempts to implement massively parallel learning models is that higher-order abstractions might be developed at the same time as lower-order ones. These higher-order representations could indeed have great psychological salience and could be used to override relations suggested by lower-order information. For example, Cheng and colleagues have shown how first-order correlational information might be overridden by second-order information which is abstracted simultaneously (Cheng & Lien, in press). Such models are compatible with an abstract to concrete shift even though they derive from an empiricist perspective.

In the next section, we will attempt to establish the existence of a shared, but primarily incorrect assumption among researchers of the dominance of a concrete to abstract shift in the development of biological thought. This shared assumption underlies much of the controversy surrounding children's ability to reason biologically.

5. Children's understanding of biological mechanisms

Investigations of children's understanding of biology have produced strikingly contradictory accounts of what children know and how their beliefs develop. However, most agree on at least one point: even young preschoolers can consistently discriminate animate and inanimate objects (Carey, 1985; R. Gelman, 1990; R. Gelman, Spelke, & Meck, 1983; Massey & R. Gelman, 1988). More specifically, young children can discriminate animals and artifacts (e.g., Carey, 1985; R. Gelman, Spelke, & Meck, 1983).[1] Of course, many artifacts are also capable of self-produced motion and are therefore animate in some sense, but even in these cases children can discriminate animals and artifacts (see S.A. Gelman & Gottfried, 1993).

Most of the debate on children's understanding of biology has focused on children's understanding of biological mechanisms. For example, Carey (1985) has argued that children have little or no knowledge of the internal workings of animals. From her evidence, she concludes that prior to about 10 years of age children lack a system of biological knowledge that is distinct from their knowledge of physics and social interaction. On the other hand, S.A. Gelman and colleagues (e.g., S.A. Gelman & Gottfried, 1993; S.A. Gelman & Markman, 1986, 1987) find that children are able to override perceptual similarity when generalizing an unseen property from one exemplar to another. Her evidence suggests that children have a distinct system of biological knowledge by preschool and that they are aware of the importance of category membership in determining which properties belong with which exemplars. Thus, one group of researchers suggests that preschoolers have an elaborate intuitive biology, distinct from intuitive physics and psychology, whereas other groups argue that biological theories develop from intuitive psychology and are absent during early childhood. The next several sections review research on children's understanding of biology and biological mechanisms to try to understand and explain this apparent conflict.

6. The animal/artifact distinction

Despite considerable disagreement about children's concepts of living things, it is widely accepted that children can discriminate animals and artifacts. For example, Carey (1985) found that children as young as 3 or 4 years "attribute animal properties of various sorts only to animals, and not to inanimate objects much like animals (e.g., dolls, stuffed animals)" and the "inductive projection of newly taught internal organs is constrained by

[1] Although there is general agreement that children can discriminate animals and artifacts, there is substantial disagreement about children's ability to discriminate living and non-living kinds. Most of this controversy surrounds children's inaccurate classification of plants as non-living things or as a third class of objects, distinct from both living and non-living things. In this paper, we will focus primarily on children's understanding of insides. As a result, it would have been difficult to incorporate plants into the design (see methods sections). Other than trees, most plants do not have clearly defined, volumetric parts visible at a macroscopic level. Thus, we were unable to portray the insides of plants in the same way we did for animals and complex artifacts. Although we were unable to include plants in our design, there is a suggestion from other research that preschoolers treat plants just like animals in terms of the sorts of part transformations they deem central to being a kind of animal or plant (Keil, 1994). The sorts of dimensions or parts that, when changed, create the need for a new label are quite similar for animals and plants and different for artifacts. For example, color changes are deemed irrelevant for most artifacts, but causally central to all living kinds (Keil, 1994).

the distinction between animals and non-animals, in the sense that only animals are credited with having the organ" (p. 183). R. Gelman et al. (1983) support this conclusion. They conducted interviews with preschoolers to determine which sorts of properties, actions, and states children would attribute to animals, people, rocks, and dolls. In general, they found that "preschool children have organized knowledge about animate and inanimate objects and that they can use this knowledge to classify correctly a variety of animate and inanimate objects" (p. 313).

Children's causal explanations for the difference between animals and artifacts also seem to be early emerging. For example, preschoolers can accurately judge whether a photographed unfamiliar object can move itself (Massey & R. Gelman, 1988). Thus, children know that animals are capable of self-generated motion but artifacts typically are not. Preschoolers expect the cause of animal motion to be internal, but show surprise when artifacts move on their own (S.A. Gelman & Gottfried, 1993). Preschool children also know that animals get larger with age and that artifacts do not (Rosengren, S.A. Gelman, Kalish, & McCormick, 1991). Thus, preschoolers know that natural transformations such as growth are lawful and domain specific. Although this finding says little about children's understanding of the mechanisms involved in growth, it does demonstrate that they have some knowledge of the innate potential of animals to become larger and that they discriminate animals from artifacts along this dimension. Finally, children know that animals are not created by people and that events such as motion are caused by internal, unseen properties for animals but by human intervention for simple artifacts. Children seem to be aware of the causal role played by internal parts in the self-generated motion of living kinds (S.A. Gelman & Kremer, 1991).

By the end of the third year of life, children believe that animals and artifacts move in different ways and undergo different sorts of canonical transformations. In addition, they know that unobservable internal parts play some role in this distinction. However, these expectations for differences between animals and artifacts may not depend on familiarity with the insides of animals and machines. That is, children may have the abstract expectation that insides are important to the distinction between animals and artifacts without having any specific knowledge of the nature of insides and how they cause phenomenal properties.

Again, there is an important difference between not knowing a particular mechanism and not having a systematic way of understanding biological phenomena that is distinct from explanatory frameworks for non-biological phenomena. Researchers who tacitly adopt some version of a concrete to abstract shift in models of how biological thought develops may feel compelled to deny the existence of a distinctly biological form of understanding to young children. Given the assumption of a concrete to abstract shift, children whose notions of mechanism are underspecified cannot have an explanatory framework that is specific to biological phenomena. Alternatively, a description of development based on an abstract to concrete shift predicts the existence of a set of expectations that are distinctly biological and that do not rely on specific knowledge of underlying mechanisms. This abstract explanatory framework may constrain the set of mechanistic explanations considered by a child without specifying a particular mechanism. The abstract framework could be specifically biological if it generates a distinct class of allowable mechanisms that differ from expectations produced by a physical or psychological framework. Preschool children may therefore have abstract expectations for differences between animals and artifacts – expectations that represent the basis of a distinctly biological mode of thought. The same children might lack concrete knowledge of the insides of animals and artifacts, suggesting that development of biological thought primarily shifts from abstract to concrete rather than concrete to abstract.

7. Knowledge of insides and distinctly biological thought

According to models based on a concrete to abstract shift, if children had knowledge of, or expectations for, the insides of different sorts of objects (especially animals), then they could form abstract theories of biology based on knowledge of the constituents. However, if they lacked such knowledge, they could not form the appropriate abstractions and therefore could not have an autonomous biology; if children knew nothing about the insides of animals, they could not form a biologically causal model of any biological process. On the other hand, the abstract to concrete view suggests that general expectations for the behavior of biological organisms may exist prior to knowledge of the specific components underlying those biological mechanisms.

Several of the studies mentioned earlier in this paper have addressed the issue of children's understanding of insides (e.g., Carey, 1985; R. Gelman, 1990; R. Gelman et al., 1983; S.A. Gelman & Wellman, 1991). Research on children's understanding of biology has typically used either an induction paradigm (e.g., Carey, 1985; Inagaki, 1989; Inagaki & Sugiyama, 1988) or a category versus similarity paradigm (e.g., S.A. Gelman & Markman, 1986, 1987). In the induction paradigm, children learn the name of an unfamiliar, internal part (e.g., omentum) and then decide whether each of a number of different animals and objects have that internal part. The critical question is whether children limit their inductions based on biological principles and taxonomies or if they use some other criteria such as behavioral or physical similarity to humans (a "psychological" response). In a typical category versus similarity task, children are shown an object (either animate or inanimate) and the object is labeled. Next, they are told about an organ or part that the target object has and they are asked which of several other objects might have that part. Generally, the test objects vary in similarity of appearance to the target and also in whether they are given the same label as the target. Thus category membership can be pitted directly against similarity to test children's understanding of the role of biological category in determining internal structure.

Research using the induction paradigm has raised substantial questions about children's knowledge of insides. Carey (1985) found that children's inductions are based less on biological principles or categories (e.g., generalizing to all animals and only animals, or all mammals or only mammals) and more on behavioral similarity to humans. Her results seem to show that young children lack a clear understanding of the category boundaries that limit generalizations. As we noted above, children do seem to discriminate animals and artifacts; they do not generalize animal parts to inanimate objects (i.e., to objects without behavioral dispositions). Carey takes these findings as evidence that before age 10, children lack an understanding of the functional internal workings of living things and therefore lack an autonomous theory of biology.

Carey's findings gain some apparent support from other research using a similar induction paradigm (Inagaki, 1989; Inagaki & Hatano, 1987, 1991; Inagaki & Sugiyama, 1988). Inagaki and colleagues have shown that young children do indeed base their attributions of an unfamiliar, physical property on the perceptual similarity of the target object to humans. However, Inagaki and Sugiyama (1988) showed that even adults base their responses on "phylogenetic" similarity to humans when mental properties are substituted for physical ones. They suggest that attributions based on perceptual similarity are the default even for adults, but with experience, people are able to constrain their inductions based on acquired category knowledge. The reliance on a default explanatory system has also been shown in preschool children (Vera & Keil, 1988). The presence of a default bias of perceptual similarity does not preclude the existence of other explanatory frameworks. A greater tendency to use a person analogy does not automatically entail an inability to have biological thought. Inagaki and colleagues argue that children adopt a naive form of vitalistic explanation for biological things and not for artifacts, suggesting an autonomous biology. Thus, even if insufficient knowledge of constituent parts precludes a mechanistic explanatory system, children can still have a biological explanatory framework. Preschoolers also seem to abandon the person analogy and draw inductions based on what appears to be a biological explanatory system when they are taught the functional role played by the taught property (Vera & Keil, 1988).

Researchers using the category versus similarity approach have tended to agree with Inagaki in arguing for the existence of autonomous domain of biology in preschool children. This approach has shown that children as young as 3 years are able to override perceptual similarity and attribute internal properties on the basis of category membership. For example, preschool children can use category information to infer the presence of unseen internal properties in the face of conflicting perceptual information (S.A. Gelman & Markman, 1986). In addition, children can tell which properties should be inferred from category information. Even when the original target is not labeled, children try to determine the category membership of the test pictures and to draw inferences accordingly, although this effect is smaller than with labels (S.A. Gelman & Markman, 1987). Preschool children seem to have beliefs about the sorts of properties that support inductions based on category membership as well as the belief that categories are particularly important tools for further discovery.

Although S.A. Gelman and Markman's (1986, 1987) studies showed that children rely on category information to infer internal properties, their research focused on natural kinds and did not examine inferences about the internal structure of artifacts. S.A. Gelman and O'Reilly (1988) addressed differences in inductions to natural kinds and artifacts as well as differences between the abstractness of the relationship between the target and the test pictures. In general, all children drew more inferences to members of the same superordinate category (including atypical members) than to unrelated categories, and all children showed a strong expectation that members of the same basic level category share internal properties. None of the children thought an unrelated object shared the internal properties of the target picture. S.A. Gelman and Coley (1990) extended these findings to 2-year-old children and found that toddlers were able to use category information rather than perceptual similarity when pictures were labeled. Thus category names set up expectations for greater similarity of internal structure. Their findings suggest that "even before children can make use of subtle perceptual cues to determine category membership, they readily use category labels as the basis of their inferences" (p. 803).

In a different experimental paradigm, preschoolers seem to lack a clear understanding of the importance of insides in determining identity (Keil, 1989). When children are shown a picture of a living kind (e.g., a skunk) and told about a surgical operation in which the living kind's appearance was changed so that it looked like another animal (e.g., a raccoon), 7-year-olds think that the animal is still a skunk whereas 4-year-olds tend to believe it is a raccoon. Thus, preschool children seem to be tied to appearance whereas 7-year-olds can reason abstractly and are not misled by appearances. However, when the same photographs are used, but the children are told that the animal is putting on a costume rather than undergoing an operation, even the younger children believe that the animal is still a skunk (Keil, 1989).

Although Keil's results suggest that preschoolers lack a clear understanding of the importance of insides for membership in a kind, S.A. Gelman and Wellman (1991) modified Keil's task and found that children considered insides to be important to the identity of animals. They contrasted two sets of items: one for which insides are relevant (e.g., animals) and one for which they are not (e.g., containers). Children of all ages reported that identity had changed when the insides were removed from the inside-relevant items. In addition, the same pattern of results held when children were asked about the function of the object after the transformation: children considered insides to be more important than outsides for the inside-relevant items. Preschool children "appreciate the special importance of insides for an object's identity and how it functions" (S.A. Gelman & Wellman, 1991, p. 229); something about the insides is critical to identity. These results and those found by Keil can be integrated by assuming that young children do know that some sorts of insides are critical to an animal's proper functioning, but are much less clear on the role of insides in individuating related animals. Thus a child might well believe that a zebra without any insides is no longer a zebra, but not be nearly as sure as to how zebra and horse insides help distinguish the two, especially in the face of different classes of competing surface changes.

In summary, Carey and others argue that children lack an autonomous domain of biology before about 10 years whereas S.A. Gelman, Wellman, and others argue that preschoolers have clear expectations for the nature of biological things. An alternative view suggests that understanding of the specific biological nature of insides develops throughout early childhood, but that some biological specificity is present from an early age (Keil, 1989). While Carey argues that children before age 10 attribute unobservable properties on the basis of the similarity of a target animal to humans, Inagaki and colleagues rely on similarity only as a default bias. They agree that children lack a mechanistic explanatory system, but argue that children reason vitalistically about biological and only biological things. Thus, children may have a biological explanatory framework much earlier than suggested by Carey. S.A. Gelman and colleagues show that young preschoolers accurately infer the existence of internal properties on the basis of category information and that they can override perceptual similarity in order to do so. Thus, some researchers suggest that children have a fairly good understanding of the importance of insides by early preschool age and others argue that children lack an understanding of the functional nature of insides until early to middle elementary school age.

All of these studies provide important insights into children's expectations and explanations. The critical task for this paper and for future research is to find a way to integrate these disparate conclusions. One commonality among the reviewed studies is the assumption of the dominance of some form of a concrete to abstract shift in children's understanding of biology. This assumption is perhaps most evident in Carey's finding that children initially base their inductions solely on perceptual similarity and only later form an abstract representation of the integrated biological system. According to Carey, a biological explanatory framework requires factual knowledge about specific organs and their functions. Once children have acquired this information, they can form a more abstract explanatory system to make further predictions about unseen properties. A common interpretation of

S.A. Gelman's findings also assumes the existence of a concrete to abstract transition. Although Gelman does not argue that children understand the functional role of internal organs, she finds that they can use category information to override perceptual similarity. Thus, Carey finds that children lack specific knowledge of internal parts and this leads to the conclusion that children cannot have an abstract, specifically biological explanatory framework. On the other hand, Gelman's findings that children are able to make inferences based on abstract category information often lead to the conclusion that children have progressed beyond perceptual similarity in their explanations.

We suggest that these contradictory conclusions can be integrated into a coherent picture by assuming an abstract to concrete shift in children's biological expectations. Although children's first experiences with animate and inanimate objects are perceptual, they might immediately form abstract expectations and only later fill in the concrete details. In the case of biological knowledge, children may hold abstract beliefs about the sorts of mechanisms operating in living kinds as opposed to artifacts. They may hold abstract beliefs that allow for specifically biological explanations, despite the absence of any concrete knowledge of the internal structure of animals. For example, children may hold an abstract expectation that animals must have some sort of functional architecture in order to move, but they may not have any concrete knowledge of the parts responsible (they would therefore believe that an animal would no longer exist as such it its insides were removed). Eventually, children learn some of the concrete details of the system and something about the sorts of parts that underlie this architecture. In this sense, children may have abstract, specifically biological expectations before they have any knowledge of the details of the system.

In the next section, we describe several new studies that address the issue of what children believe is inside animals and machines. Despite all of the evidence on children's beliefs about what is shared among category members, we still know little about what children think is inside different sorts of things. Children might well list a number of internal properties of natural kinds and complex artifacts (e.g., machines with functional internal mechanisms). However, even if they know that animals have a heart and stomach, they may not know what functional role such organs play and they may have no expectations for the appearance of these parts. On the other hand, even if they lack labels for internal parts, they may have very clear expectations for the sorts of things that should be inside animals versus machines.

8. Children's expectations for insides: new empirical studies

The goal of all of the studies reported in this section was to determine what sorts of things children expect to be inside animals and complex artifacts (i.e., machines). Would they know, for example, that gears belong inside machines but not animals? Initially, we thought that children would be able to match pictures of the insides of animals and machines to the outsides based on perceptual similarity alone. The insides and outsides of animals tend to have similar sorts of curvature (e.g., both lack sharp vertices), and the sorts of curvature present in both the insides and outsides of animals is quite different from that of machines. Thus, if children relied on perceptual similarity, they should be able to match the insides to the outsides. Interestingly, we found that children were far less successful at this task than we expected

STUDY 1

Thirteen 3-year-olds (M = 3;7, range = 3;1–3;11) and fourteen 4-year-olds (M = 4;5, range = 4;0–4;9) saw clip-art drawings of animals and machines with one of two different sorts of insides superimposed on the drawings. Children were shown nine pairs of animals (e.g., a pair of bears) and nine pairs of machines (e.g., a pair of cars).[2] One member of each pair had computer-drawn animal insides and the other had machine insides. Because the particular drawing of insides might bias the results, three versions of the animal insides and three of the machine insides were generated and each animal and machine pair was randomly assigned a combination of these insides. Consequently, one animal pair and one machine pair had each of the nine possible combinations of machine and animal insides (see Fig. 1 for an example of an animal pair).[3]

Children were initially introduced to a toy alligator (Freddy) who had the ability to "see right through the outsides of things into the inside". Children were also told that Freddy had never been to Earth before so he sometimes got confused about what was inside different sorts of things. Children were then given two practice trials to determine whether they understood the "inside of" relation. Children were shown pairs of drawings of a refrigerator and of a closet. For each pair, one had food superimposed on it and the other had clothes. All children at both age groups responded correctly to

[2] In pilot work, we tried to include plants in the design as well. Unfortunately, the task became difficult to explain to preschool children. Most plants do not have large volumetric areas with clearly defined internal "parts". As a result, we were unable to portray the insides of plants in the same manner as animals and complex artifacts. Given these difficulties, we decided to focus exclusively on animals and machines – two classes of objects that preschoolers can distinguish quite easily.

[3] Machines used in Study 1: modern car, telephone, clock, bus, bulldozer, submarine, radio, antique car, and padlock. Animals used in Study 1: bear, frog, elephant, baboon, bulldog, sheep, fish, turtle, and zebra.

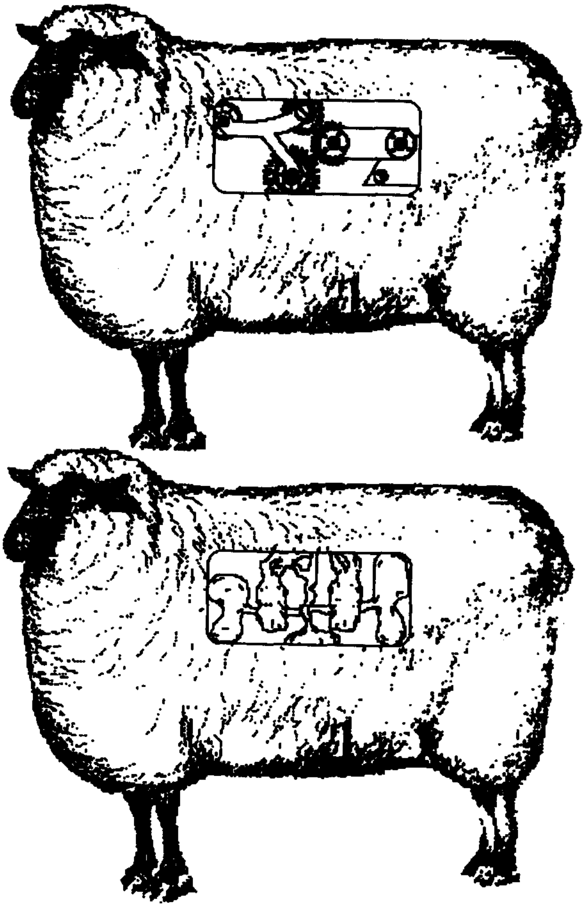

Fig. 1. Sheep with animal and machine insides.

these trials, suggesting that they understood what we meant by insides and that they understood the task itself. Following these practice trials, children were shown each of the trial pairs, in a different random order for each child, and were asked to tell Freddy "which of these drawings is a real X? Which shows a real X with real X insides?" (e.g., which shows a real sheep with real sheep insides). When children needed additional prompting, they were asked to "show Freddy which one has real X insides". Incorrect responses were not corrected.

The results of this study showed that most children do not have clear expectations for the sorts of things that are likely to be inside animals and machines. As would be expected, older subjects (M = 11.5, $SD = 3.90$) answered slightly more items correctly than younger children (M = 10.77, $SD = 3.24$), although the difference was not significant, $t(25) = 0.527$, $p =$

.3014 (1-tailed), $r = .105$.[4] Given that chance responding would produce a mean of 9 correct responses out of 18 possible items, t-tests comparing the mean for each age group to chance proved significant for both age groups (for younger subjects, $t(12) = 1.969$, $p = .0363$ (1-tailed), $r = .494$; for older subjects, $t(13) = 2.398$, $p = .0161$ (1-tailed), $r = .554$). Although the means for both age groups were significantly above chance levels of responding, the degree to which they were above chance was relatively small. In fact, only four of the younger and six of the older children responded significantly above chance levels (the proportion of children whose total scores were significantly above chance did not differ between the age groups, $\chi^2(1) = 0.3514$, $p = .553$).[5]

In general, the results suggest that children lack clear expectations for the sorts of insides that belong in animals and machines, and relatively few individual children responded at above chance levels. The lack of a difference in either the pattern of responses or the number of children responding significantly above chance between the two age groups suggests that any radical developmental changes in conceptual understanding would have to occur primarily after the age of 4 years.

Although these findings suggest that young children lack principled expectations for what should be inside animals and machines, an alternative account suggests that even children who failed to respond above chance were still responding according to a principled conceptual framework. For example, they might know that the insides of both animals and machines require some sort of functional architecture, but not which architecture is appropriate. Unfortunately, the design of Study 1 precludes any distinction between this explanation and truly random responding. A second study was undertaken to assess developmental changes in children's understanding of internal structures and to examine the possibility of other conceptual frameworks for children's responses.

STUDY 2

In this study, the computer-drawn animals, machines, and insides were replaced by scanned and laser-printed photographs in order to control for

[4] According to Rosenthal and Rosnow (1991), "effect size refers to the strength (or magnitude) or the relationship" (p. 42). Given that significance tests are a function of both the size of the effect and the number of subjects, comparisons of significance levels across conditions with different numbers of subjects can be misleading. Effect sizes allow comparisons of the magnitude of an effect across conditions. In this case, the effect size $r = sqrt[t^2/(t^2 + df)]$ where df is the degrees of freedom and $sqrt$ is the square root (Rosenthal & Rosnow, 1991).

[5] Significance ($p < .05$) was determined by assuming the trials were independent and comparing total correct scores to the binomial probability of correctly answering that many questions. Given a .50 probability of a correct response, total scores greater than 12 correct were significant.

the possibility that children's failures in the first study were due to the lack of detail in the portrayals of insides. Rather than superimposing the insides onto pictures of animals and machines, two sets of insides, each including a photograph of the insides of an animal, a machine, and an aggregate substance (e.g., a pile of rocks) were compiled and each child was randomly assigned one of the sets. The animal photographs were of the insides of a fetal pig and the machine photographs were of a large shop tool. The insides were not drawn from any of the animals or artifacts actually used in the study. Children were told that each of the photographs represented the *sort* of thing that *might* be inside some things. The photograph of the aggregate was included to allow us to distinguish chance responding from a pattern in which children know that some functional architecture is necessary, but do not have expectations for what that architecture should look like. The three printed photographs of insides were visible in front of the child throughout the task, and children were shown 10 photographs of animals and 10 of machines. Again, children were introduced to Freddy and told that he could see right through the outsides of things into the inside, and they were asked to point to the sort of insides Freddy would see if he looked right through the outside of each animal or machine. Note that in this study each trial consisted of a single animal or machine rather than a pair. Given children's apparent understanding of our use of the term "inside" (see Study 1), the refrigerator and closet practice items were not used in this task. Instead, all children saw four practice trials, consisting of two animals and two machines, followed by the 20 test photographs, thoroughly shuffled for each child, with the constraint that animals and machines were seen on alternate trials. Again, no feedback was given. Participants in this study were 22 3-year-old (M = 3;10, range = 3;4–4;5), 24 4-year-old (M = 4;9, range = 4;4–5;6), and 24 8-year-old children (M = 8;2, range = 7;6–9;0).

The analysis for Study 2 was more complex than for Study 1 because each child could choose one of three options for each animal or machine photograph (i.e., animal insides, machine insides, or aggregate material). This design allows a more detailed view of children's patterns of responding. Overall, the total number of correct responses increased with age (see Tables 1 and 2), with 8-year-olds correct significantly more often than either of the younger groups. The younger groups did not differ significantly.

Again, the mean total score for all three age groups was significantly greater than chance, and a number of individual children at each age group exceeded chance as determined by comparison to a binomial probability distribution (with probability of a correct response = 1/3, see Table 1). However, this analysis may provide a misleading view of children's performance. Children need not have an adult understanding of the nature of insides in order to demonstrate above chance responding; they only need to answer 11 out of 20 questions correctly to exceed chance at $p = .05$. In fact, a subject who responded by choosing the animal insides for all 20 photographs (a perseverative bias) would exceed chance at $p = .10$. This analysis

Table 1
Means and standard deviations for the total number of correct responses and comparisons against chance for Studies 2–5

Study	Mean (*SD*)	*t*-test	No. of subjects > chance[a]
Study 2			
3 years ($n = 22$)	12.27 (5.50)	$t(21) = 4.777$**	12 out of 22
4 years ($n = 24$)	14.33 (4.89)	$t(23) = 7.685$***	18 out of 24
8 years ($n = 24$)	19.00 (1.84)	$t(23) = 33.355$***	24 out of 24
Study 3			
4 years ($n = 24$)	13.46 (4.79)	$t(23) = 6.945$***	17 out of 24
Study 4			
4 years ($n = 18$)	11.67 (4.75)	$t(17) = 4.46$**	10 out of 18
Study 5			
4 years ($n = 18$)	10.78 (5.83)	$t(17) = 2.993$*	8 out of 18

[a] The total score for each child was compared to the binomial probability of correctly answering that many questions given a probability of 1/3 for a correct response for each item. This analysis assumes that all trials are independent.
*$p < .005$; ** $p < .0005$; ***$p < .00001$.

may reveal little more than the fact that children were typically responding systematically. In addition, it says little about the sorts of mistakes that subjects made. By 8 years of age, most subjects respond accurately to both animal and machine photographs, but a single significance test against a single value of chance cannot reveal patterns of development.

In order to determine the typical patterns of response at different ages, we identified a set of 10 possible distributions of responses that would be potentially interesting (see Table 3). One of these patterns represented an equal distribution of responses across all three sorts of insides for both animals and machines. This pattern will be referred to as "chance" in subsequent discussion. Another pattern represented accurate responding (e.g., choosing only animal insides for animals and only machine insides for machines), hereafter referred to as "correct". Two additional patterns represented successful responses to machines (choosing gears), but incorrect responses to animals. In one of these patterns, responses to animals are equally divided among all three sorts of insides, suggesting a lack of any

Table 2
Individual *t*-tests comparing the total number of correct responses at each age in Study 2

Age	*t* value	*p*	Effect size
8 years vs. 4 years	$t(46) = 4.35$	$p = .00004$	$r = .540$
8 years vs. 3 years	$t(44) = 5.63$	$p = 5.88 \times$ E-7	$r = .647$
4 years vs. 3 years	$t(44) = 1.34$	$p = .0936$	$r = .198$
Main effect of age	$F(2, 67) = 14.49$	$p = 5.895 \times$ E-6	$\eta = .549$

Table 3
Theoretically interesting patterns of responding used for classifying patterns of individual children (A = animal insides, M = machine insides, S = aggregate substance)

(1) Correct responding

	Responses to insides		
Outsides photographs	A	M	S
Animal	10	0	0
Machine	0	10	0

(2) Chance responding

	Responses to insides		
Outsides photographs	A	M	S
Animal	3.3	3.3	3.3
Machine	3.3	3.3	3.3

(3) Machines correct 1 (animals incorrect but not machine insides)

	Responses to insides		
Outsides photographs	A	M	S
Animal	5	0	5
Machine	0	10	0

(4) Machines correct 2 (animals incorrect and equally distributed)

	Responses to insides		
Outsides photographs	A	M	S
Animal	3.3	3.3	3.3
Machine	0	10	0

(5) Animals correct 1 (machines incorrect but not animal insides)

	Responses to insides		
Outsides photographs	A	M	S
Animal	10	0	0
Machine	0	5	5

(6) Animals correct 2 (machines incorrect and equally distributed)

	Responses to insides		
Outsides photographs	A	M	S
Animal	10	0	0
Machine	3.3	3.3	3.3

Table 3 (*Continued*)

(7) Functional architecture

	Responses to insides		
Outsides photographs	A	M	S
Animal	5	5	0
Machine	5	5	0

(8) Animal response bias

	Responses to insides		
Outsides photographs	A	M	S
Animal	10	0	0
Machine	10	0	0

(9) Aggregate response bias

	Responses to insides		
Outsides photographs	A	M	S
Animal	0	0	10
Machine	0	0	10

(10) Machine response bias

	Responses to insides		
Outsides photographs	A	M	S
Animal	0	10	0
Machine	0	10	0

expectations for the sorts of things that could be inside animals. In the other pattern, gears are rejected and responses to animals are equally divided between the animal insides and the aggregate. Such a pattern would suggest an understanding that the sorts of things that belong inside animals and machines differ (corresponding patterns with animals correct and machines incorrect were also included). We also included a pattern in which aggregates are rejected for both animals and machines, but responses to both animals and machines are equally distributed between animal and machine insides (a "functional architecture" pattern). The remaining three patterns included all three possible perseverative biases (e.g., consistently picking the animal insides for both animals and machines).

For each child, we computed the sum of the squared deviations from each pattern to determine the pattern that most closely matched each subject's responses. Given that some patterns are more likely given chance responding, a Monte Carlo simulation of 50 000 cases was conducted. For each pattern, these 50 000 cases were ranked according to the sum of the squared deviations from each pattern. Thus, for each pattern, we had a rank order of 50 000 randomly chosen cases which represents a probability distribution for each pattern. By comparing each child's score (for each pattern, the sum of squared deviations) to the distribution for each of the 10 patterns, we could assign a probability that the child would have a score as closely matched to each pattern given chance responding. That is, each child could be assigned to the pattern that would be least likely given chance responding.[6]

As expected, the number of subjects matching a totally correct pattern increased with age (see Table 4). However, it is interesting to note that

Table 4
Number of subjects from each age group in Study 2 fitting each pattern along with average p value for subjects in that pattern

	Age group		
Pattern	3 years ($n = 22$)	4 years ($n = 24$)	8 years ($n = 24$)
(1) Correct	10***	12***	22***
(2) Chance	2*	1*	0
(3) Machines–not animals (animal and aggregate)	2***	5***	2***
(4) Machines–not animals (all insides for animals)	1*	0	0
(5) Animals–not machines (machine and aggregate	0	0	0
(6) Animals–not machines (all insides for machines)	0	2*	0
(7) Functional architecture	1*	1*	0
(8) Bias–animal	3**	2*	0
(9) Bias–aggregate	1***	0	0
(10) Bias–machine	0	0	0
No pattern[a]	2	1	0

Note: Average probability was calculated by computing the Z value for each subject in that pattern (based on the probability of that close a match given random responses), averaging the Z scores, and computing the probability of that Z. See Table 3 for definitions of the patterns.
[a] Children whose responses did not fit any of the 10 patterns closely.
$^*p \leq .05$; $^{**}p \leq .005$; $^{***}p \leq .0005$.

[6] It is important to note that the set of patterns chosen as theoretically interesting may influence the classification of children's patterns of responding. For example, a child classified as showing "correct" responding (see pattern 1) when compared to the set of alternative patterns we defined might not be classified the same way given a different set of alternative patterns. However, the patterns we identified seem to encompass all of the theoretically interesting alternatives, and they fit children's patterns of responding fairly well. Although the set of patterns chosen may lead to slightly different conclusions, this approach suggests ways in which children's scores differ from chance responding rather than simply determining that they do (i.e., a typical significance test comparing a child's score to some measure of chance is roughly equivalent to conducting a pattern analysis with only two of the patterns we have identified: namely, "chance" and "correct").

relatively few subjects closely matched a chance pattern of responding. This difference in patterns of responding across ages was significant, $2\chi^2(2) = 13.075$, $p = .0014$ (this analysis compares differences in the number of children at each age group showing patterns of correct responding or any other pattern of responding), confirming the analysis presented in Table 2. By 8 years, nearly all subjects respond accurately, whereas only about half of the 3- and 4-year-olds were best matched by the correct pattern. This developmental trend is particularly interesting given that relatively few children at any age show "chance" responding. Children at all ages are responding systematically (see below), but by 8 years of age they have more precise, concrete knowledge of the sorts of things that can be inside animals and machines.

Of the children who did not match "chance" or "correct" patterns, only two of the 70 children matched a "functional architecture" pattern. Almost all of the remaining children (specifically, two 3-year-olds, five 4-year-olds, two 8-year-olds) responded correctly to the machine targets, but equally divided their responses to animals between the animal insides and the aggregate (one additional 3-year-old correctly responded to machines but equally divided responses to animals among all three alternatives). None of the children in this study showed the pattern in which animal targets were answered correctly while responses to machines were split between machine insides and the aggregate (although two 5-year-olds correctly answered the animal targets but responses to machines were equally divided among all three alternatives).

Even with the increased realism and detail photographic stimuli, many preschool children were unable to match appropriate insides to animals and machines. Fewer than half of the children were consistently correct, but responses of many of the other children did not appear to be random. By 8 years, nearly all children know which insides belong with animals and machines. This finding does not establish older children's knowledge of what insides are like, yet it suggests that they know that some things are more likely to be in animals than machines and vice versa; at minimum, they expect different sorts of things to be inside animals and machines and they have some general ideas about what those sorts of things should look like. One implication of this finding is that children of all ages may have abstract expectations for the sorts of things that can be inside animals and machines, but they lack experience with concrete examples of insides. By 8 years, children have had more experience with insides, and can incorporate concrete information into their explanatory frameworks. Although the primary developmental trend may involve exposure to concrete information about insides, young children may have some knowledge of concrete details as well. Concrete knowledge, however, is not necessarily a prerequisite of abstract thought.

The unexpected result that many of the children correctly responded to the machine photographs but not the animal ones could mean several things. First, children probably learn about the insides of machines before they learn about the insides of animals; they likely have more experience with the insides of toys and machines than they do with the insides of animals. Their experience leads them to believe that only certain sorts of things are likely to be in machines, but they lack knowledge of the insides of animals. Thus, one possible interpretation of the finding is that children were responding according to a task demand. Assuming they correctly pick the machine insides for the machine photographs and exclude machine insides for animal photos, children would be left with two possible alternative insides for the remaining trials. Even if they knew which choice was correct for animals, they may feel pressure to pick the aggregate substance on some trials. In other words, placing three photographs in front of the child leads to a task demand to pick all three at some time. They know what belongs in the machine and they are less certain about the animal. As a result, they sometimes pick the aggregate substance as the insides of animals.

However, even if children respond according to this task demand, the findings still reveal an understanding of the nature of the insides of machines. In addition, children seem to know that machine insides are different from animal insides, whether or not they know what the insides of animals are like. Although the demand interpretation seems like a strong explanation for this unusual pattern of responding, if these children truly understood the nature of the insides of animals but were responding according to task demands, they should respond correctly more often in the first half of the task than the second. That is, they should respond correctly until they begin to realize that none of the photographs have the aggregate substance inside. At that point, they should begin to pick the aggregate on some trials. An analysis of the data comparing the number of aggregate responses to animal targets in the first and second half of the session for children showing this sort of pattern revealed no such differences. Of the nine children showing this pattern, four chose the aggregate more in the first half of the trials and three chose the aggregate more in the second half (two children chose the aggregate an equal number of times in the first and second half of the trials). Even those children choosing the aggregate more in the second half of the trials often picked the aggregate in the first 10 trials, and the difference between the number of aggregates picked in each half of the data was never more than two items. These findings suggest that children were not adjusting their responses according to task demands. Two alternative interpretations of this unusual pattern of responding are addressed in the studies described below.

STUDY 3

One possible explanation for preschool children's relatively poor performance in Study 2 is that two-dimensional photographic depictions of animal insides may still be too poor a representation. Perhaps the information children use to identify the insides of animals depends crucially on depth information (or texture or shading, etc.). In order to eliminate any abstractions in our representation of insides, we conducted another study in which photographs of insides were replaced with glass jars containing machine insides (gears, dials, wires, etc.), preserved animal insides (the abdominal organs of two cats), or aggregates (small white rocks) suspended in gelatin. Other than the substitution of a single set of jars for the two sets of photographs (i.e., all children saw the same set of insides), the methods of this study were identical to those of Study 2. Twenty-four 4-year-old children (M = 4;11, range = 4;4–5;5) participated in this study. This age group was tested primarily because their responding was slightly more orderly than the 3-year-olds, and we thought that the increased realism of the jars would be more likely to help the 4-year-olds than the 3-year-olds.

In general, the results with jars were very similar to those with photographs. Subjects in this experiment responded correctly slightly less often ($M = 13.46$, $SD = 4.79$) than the 4-year-olds in Study 2 ($M = 14.33$, $SD = 4.89$), but the difference was not significant, $t(46) = .626$, $p = .534$ (2-tailed). As in Study 2, the mean total correct score was significantly greater than a chance value of 6.67 correct, and a number of children answered a significant number of items correctly (see Table 1). However, the reader will recall that a comparison against chance may not be particularly informative. Using the same pattern analysis as in Study 2, 11 subjects were consistently correct and none of the children closely matched a chance pattern. Again, four subjects correctly responded to machines but equally divided their responses to animal photographs between the animal insides and the aggregate. However, two children correctly responded to the animals but equally divided responses to machines between the machine insides and the rocks (one additional child correctly responded to animals and equally divided responses to machines among all three alternatives). Two of the subjects excluded the rocks, but failed to discriminate between animal and machine insides (see Table 5).

These results are fairly consistent with those of Studies 1 and 2. The patterns of responses of 4-year-olds in Study 2 and the children in this study were nearly identical. A test comparing the number of subjects in each study responding with a correct pattern, or a machine but not animal correct pattern, did not approach significance, $\chi^2(1) = 0.0298$, $p = .863$. Even with the realism and detail of actual insides, only half of the children matched the correct pattern, but as in Study 2 many of the children still showed an ordered pattern of responding. Given the vividness of the jars of insides, this finding provides even stronger evidence that many preschool children lack a clear understanding of the sorts of insides that belong in animals. At the very least, this study suggests that children's failures in earlier tasks have little to do with the quality of the stimuli. The results with photographic stimuli and with jars of insides were nearly identical.

Table 5
Patterns of responding of 4-year-olds in Studies 2-5, along with average *p* value for subjects in that pattern

	Study			
Pattern	Study 2 ($n = 24$)	Study 3 ($n = 24$)	Study 4 ($n = 18$)	Study 5 ($n = 18$)
(1) Correct	12****	11****	5****	7****
(2) Chance	1**	0	1**	0
(3) Machines-not animals (animal and aggregate)	5****	4***	4***	1**
(4) Machines-not animals (all insides for animals)	0	0	1***	0
(5) Animals-not machines (machine and aggregate)	0	2****	1****	2***
(6) Animals-not machines (all insides for machines)	2**	1****	0	1***
(7) Functional architecture	1**	2**	1**	0
(8) Bias-animal	2**	0	0	0
(9) Bias-aggregate	0	0	1*	4**
(10) Bias-machine	0	1**	1**	0
No pattern[a]	1	3	3	3

Note: Average probability was calculated by computing the Z value for each subject in that pattern (based on the probability of that close a match given random responses), averaging the Z scores, and computing the probability of that Z. See Table 3 for definitions of the patterns.
[a] Children whose responses did not fit any of the 10 patterns closely.
$^{*}p \leq .10$; $^{**}p \leq .05$; $^{***}p \leq .005$; $^{****}p \leq .0005$.

STUDY 4

Although the findings from the first three studies present striking evidence that children lack a clear conception of insides, R. Gelman (1979) and others have argued that children think about insides in terms of the functions they serve. Perhaps children in our tasks failed because we did not emphasize the role the insides served for the machines and animals. If children reason according to the innards principle (R. Gelman, 1979), they know that many physical processes (e.g., motion) depend on the interaction of unseen constituent parts. If children's expectations for the insides of animals and machines depend on the functional role those insides serve, children may have failed in our tasks because we did not emphasize such functions. In this study, our methods were identical to those of Study 3 except that we emphasized the functional role of the insides. For example, we asked children which sort of insides would help a bear do bear-like things such as walking and climbing trees and having bear babies. A new group of 18 4-year-old children participated in this study (mean age = 4;6, range = 4;0-5;1).

The results of this study were comparable to those of the previous two studies. The mean number correct in this study (M = 11.67, $SD = 4.75$) was comparable to that of Study 3, $t(40) = 1.20$, $p = .236$, and the difference between the 4-year-olds in Study 2 and those in the current study was only marginally significant, $t(40) = 1.77$, $p = .084$. Again, the mean was greater than chance and a number of children were correct at greater than chance levels (see Table 1). An analysis of the individual patterns of responding produced a result similar to those of Studies 2 and 3 (see Table 5 for distribution of patterns). However, relatively fewer children in this study closely matched a correct pattern. Only one child matched a chance pattern, and four children correctly answered the machine questions but not the animal questions. A chi-square test comparing the distribution of patterns of responding in Studies 3 and 4 (with and without emphasis on function) revealed no difference in the distribution of individual patterns of responding, $\chi^2(1) = .800$, $p = .371$ (this test compares the number of subjects matching the correct pattern and the machines–not animals pattern). Emphasizing the functional role of the insides for each animal or artifact had little if any effect on children's patterns of responding. In fact, any differences were in the wrong direction; slightly fewer subjects matched the correct pattern when we described the function of the insides. Thus, children's failure to correctly choose the insides of animals and machines cannot be attributed to a failure to emphasize function.

STUDY 5

One final possibility is that children are able to use their knowledge of the distinction between natural kinds and artifacts to pick the appropriate insides for machines. That is, children match artifact insides with artifact outsides and natural kind insides with natural kind outsides. By using this distinction, children would know that gears belong in machines, but might not be able to tell whether the animal insides or the aggregate substance belongs in an animal. In Study 2, the aggregate substance photographs both depicted non-living natural kinds (e.g., dirt and rocks). In this study, we tested whether this pattern of responding, correctly responding to machines but not animals, can be eliminated by substituting artificial substances for the aggregate substances of Studies 2, 3 and 4. Given that patterns of responding to jars of insides were nearly identical to those with photographs, a single set of photographs of insides was used in this study. The procedure was identical to that of Study 2 with the exception that a single group of 18 4-year-old children (M = 4;4, range = 3;11–4;11) were tested using a single set of photographs. In this study, the photograph of an aggregate substance was replaced by a photograph of a randomly arranged pile of blocks.

On average, subjects in Study 5 (mean total correct = 10.78, $SD = 5.83$) were less accurate than those of Study 2, $t(40) = 2.149$, $p = .038$. The mean total correct score was still greater than chance and a number of children responded more accurately than would be expected by chance. In order to assess the impact of substituting an artifact aggregate for the natural kind photograph in Study 2, we again analyzed children's patterns of responding (see Table 5). Of the subjects fitting one of the 10 patterns, seven were closest to the totally correct pattern, none closest to the chance pattern, and only one correctly responded to the machine, but missed the animals. Given the relatively small expected frequencies of the cells, a Fisher's exact test was computed, using the adjustment procedure recommended by Rosenthal and Rownow (1991) to compensate for overly conservative probability estimates given by the exact test. The results of this test (comparing the number of subjects from the 4-year-olds of Study 2 and from this study who matched a correct pattern and a machines–not animals pattern) suggested that changing from rocks to blocks decreased the number of children correctly responding to machines and missing animals, but the difference was not significant, $Z = .759$, $p = .224$. Perhaps children are aware of the distinction between natural kinds and artifacts and can use this distinction to guide their expectations for what could be inside different sorts of things. If so, then more children in this study should have responded correctly to the animal targets and equally divided their responses to machines between the blocks and the machine insides. An adjusted Fisher's exact test compared the number of 4-year-olds in Study 2 and the number of children in this study who showed machine–not animal patterns and animal–not machine patterns. This difference in the distribution of patterns was significant ($Z = 1.834$, $p = .0333$), suggesting that children who correctly responded to one sort of target used their knowledge that machines are artifacts and animals are natural kinds to determine potentially appropriate sorts of insides.

In Studies 2–4, knowledge of the distinction between natural kinds and artifacts would lead children who were uncertain about the insides of animals and machines to correctly pick the machine insides for machines because it was the only artifact. They would then pick either of the natural kinds as the insides of animals. In Study 5, the same knowledge of artifacts and natural kinds would lead uncertain children to correctly respond to animal photographs but to pick either of the artifacts as the insides of the machines. Clearly not all children use such a strategy, but of the children not matching a totally correct pattern this strategy seemed to be the most common.

GENERAL DISCUSSION

Our studies showed that children expect the insides of animals and machines to differ, but they lack expectations for the specific physical appearance of those insides. Although they consistently pick different insides for animals and machines, they tend to divide their responses to one class of objects among two different sorts of insides. In addition, they consistently choose natural kind insides (rocks or animal insides) for the animals and artifact insides (machine insides or blocks) for the artifacts. Children apparently have a set of abstract expectations that may serve to guide their search for concrete differences between animals and artifacts. By 8 years, children have acquired sufficient concrete knowledge to consistently choose the appropriate insides.

These results are consistent with a model of development in which the primary transition is from abstract to concrete thought. Our review of the literature suggested a resolution to the debate between those who claim that preschool children lack an autonomous biology (e.g., Carey, 1985) and those who believe children can reason biologically (e.g., S.A. Gelman, 1988; S.A. Gelman & Markman, 1986, 1987). A traditional concrete to abstract shift account of this controversy would lead to the claim that children often succeed on Gelman's tasks but fail on Carey's because they have sufficient concrete knowledge but lack adequate abstract knowledge. This conclusion is suspect for several reasons. First, Gelman's tasks generally do not focus on concrete knowledge of insides. Rather, they assess children's abstract knowledge of the importance of category membership in determining the contents of insides. Also, although Carey's tasks involve abstract knowledge about biological systems in general, they also focus on children's knowledge of specific biological mechanisms. Finally, our findings suggest that many preschoolers lack a clear understanding of the sorts of things that should be inside animals and machines; they lack concrete knowledge of insides. These findings were consistent across various levels of abstraction in our representation of insides and were uninfluenced by an increased emphasis on the functional role of the internal structures.

Thus, children succeed on Gelman's tasks despite a lack of concrete expectations for what should be inside different sorts of things and in spite of the fact that such tasks focus on abstract category relations rather than concrete instantiations of biological mechanisms. However, this apparent contradiction can be eliminated by assuming the dominance of an abstract to concrete shift; preschool children may have abstract ideas about the sorts of things that might underlie the differences between animals and artifacts, and only later begin to incorporate the physical processes underlying these differences into their explanatory systems. Eventually, these abstract beliefs may lead children to search for more specific information about animals and machines, and their increased understanding leads to more concrete beliefs about the nature of insides.[7]

[7] None of these distinctions could have been discovered without considering different patterns of responding. The significance tests provided in Table 1 cannot reveal distinctions such as children's expectation that animals should have natural kind insides and machines should have artifact insides. All too often, researchers are content to reject a null hypothesis without considering differences in the ways that subjects may differ from chance, or even what they consider to be chance. The pattern analysis we describe allows a more precise view of individual differences and developmental trends, and provides a more meaningful description of children's understanding.

If the notion of an abstract to concrete transition is correct, children succeed on category versus similarity tasks because they emphasize abstract categorical information and do not rely heavily on concrete knowledge of underlying mechanisms. Similarly, they tend to fail on Carey's induction task because they are unable to bring their abstract knowledge to bear on the questions they are asked. If a property induction task does not emphasize information about category membership, then children must first determine category membership in order to correctly attribute properties. By not making categories explicit, such tasks might not appeal to children's abstract knowledge because they tend to de-emphasize category differences. When categorical information is not stressed, children do seem to rely on a person analogy (e.g., Carey, 1985); children's biological thought may be masked by their inability to draw on their abstract explanatory framework for inferences about unobservable properties. When children are given category information (as in the category vs. similarity task), they are better able to infer the existence of unseen properties.

The absence of concrete knowledge of mechanisms or constituent parts underlying biological processes does not entail ignorance of the domain of living things any more than lack of knowledge of the mechanisms underlying computers entails adult ignorance of that domain. Certain levels of functional analysis that are agnostic about the particular nature of underlying mechanisms can nevertheless be successful ways of demarcating a domain and fostering powerful inductions and other patterns of domain-specific reasoning. Only by assuming a concrete to abstract shift does the absence of such concrete knowledge preclude the existence of an abstract explanatory framework. Children do use external similarity to draw inferences in some cases and they often have little knowledge of the specific mechanisms of biological processes (until the past couple of centuries, neither did biologists). Accordingly, children's biological theories are necessarily vague and inaccurate until they have been taught the current scientific models. However, even if their theories about biological mechanisms are inaccurate, children could still have an autonomous domain of biological thought, albeit a primitive and abstract one. If children distinguish between living and non-living kinds and expect different sorts of mechanisms to operate for these two classes of objects, then they have a distinct domain of biology. We presented evidence in this paper than children are able to distinguish animals and artifacts, and other research suggests that in many ways plants are treated like animals in terms of the sorts of properties that are central to their nature (see Keil, in press). Thus, we would suggest that children have an abstract, autonomous biology. They need not know the precise mechanisms that operate in order to have an explanatory framework that guides their expectations in different ways for each domain.

Atran (in press) has suggested that young children's initial knowledge of the category of living things is based on surface perceptual properties. Awareness of the category of living things constrains attempts to form a biological theory to explain properties of living things. In this paper we have argued that young children come to appreciate living things, or at least animals, as a distinct class of entities very early in development. However, this distinction is not based on a detailed understanding of underlying mechanisms. Although surface perceptual patterns are likely to be involved, other research suggests that children also gain an early appreciation of abstract patterns of causation and of differences in the sorts of properties that are causally central in different domains (Keil, 1994).

The notion that children might have a framework of causal expectations without detailed mental models of underlying mechanisms should not be too surprising because adults, as well, often have only skeletal notions of the mechanisms underlying complex natural phenomena. As described above, knowing that the elements in the periodic table are ordered into vertical columns with similar phenomenal properties which derive from the structure of their electron shells does not require notions of detailed mechanisms that might explain how electron shells result in greater or lesser electrical conductivity. People can have strong intuitions about relevant causal powers in a domain without having a detailed model of mechanism (Harré, 1988). People can have empirically supported beliefs about the sorts of properties that matter in a domain and about how some of the causal interactions are likely to come about, without knowing the precise mechanisms or architectures involved. Such abstract expectations may be especially common with biological thought where functional analyses and arguments are especially powerful, effective, and respectable (Salmon, 1989).

The approach we have taken to reconciling apparently contradictory findings within the domain of the development of biological thought may help to make sense of apparently incompatible results in other domains as well. All too often, results that appear contradictory are based on different levels of abstraction, and derive from a set of shared but inadequate assumptions. We have made the case for an abstract to concrete shift in biological thought, and we hope that our approach may lead to similar sorts of resolutions for debates within such domains as naive physics, folk psychology and moral development as well.

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