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COGNITIVE DEVELOPMENT: FOUNDATIONAL THEORIES OF CORE DOMAINS

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Contents

Cognitive development has been reviewed twice in this series in the last ten years: The first of these reviews concerned stages of cognitive development (Fischer & Silvern 1985), the second mechanisms of cognitive change (Siegler 1989). These topics reflect only two of many important themes in the field. For example, over the past ten years research with infants has increasingly

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revealed a rich set of early cognitive capacities. There has been renewed interest in instruction, including such new or reinvigorated topics as emergent literacy in the preschool years (Teale & Sulzby 1986), science understandings, and academic achievement across different nations and cultures (Stevenson et al 1986). More generally, cross-cultural studies of cognitive development (Stigler et al 1990) are of increasing importance. Cognition, intelligence, and learning in the elderly have dramatically increased their research presence with topics such as wisdom and late-life potential (Baltes & Baltes 1990), complementing earlier concern with loss of function. Reflecting increasing interdisciplinary research in psychology generally, there has been a blurring of traditional disciplinary lines in research on cognitive development. In the past several years the problematic boundaries between cognition, instruction, development, and acculturation have begun to crumble.

Two further trends in the field stand out in our minds and figure prominently in our review, namely contemporary concern with domains of cognition and with naive theories. These two topics represent a recent revolution in the study of cognitive development.

DOMAINS AND THEORIES

It is increasingly accepted that cognition may differ substantially in different areas or domains (Chomsky 1975; Fodor 1983; Gallistel 1990). Recently, arguments have been made for each of the following: a unique language-learning faculty; distinctive neuronal substrates for cognizing about space; predispositions in infancy to attend to numbers versus faces versus speech; a highly evolved primate social intelligence; specific islands of expertise, such as about dinosaurs, physics, and chess. The general claim is that the mind is in some sense compartmentalized or "modularized"; that is, that human conceptual understanding of one sort (e.g. about space) is likely to be quite different in character, structure, and development from understanding of another sort (e.g. about language).

Complementarily, investigators in disciplines such as anthropology, cognitive science, education, and developmental psychology increasingly discuss folk, naive, lay, or commonsense theories (Berlin et al 1973; Carey 1985; Karmiloff-Smith & Inhelder 1975; Murphy & Medin 1985; see Harold Kelley's chapter in this volume). Commonsense theories are nonscientists' everyday understandings of certain bodies of information such as folk zoology or naive astronomy. Various serious claims have been advanced: that human concepts are entrenched in larger naive theories; that conceptual change and thus important aspects of cognitive development are akin to theory change in science; that cultural world views are instantiated in folk theories; and that theories supplant similarity-based conceptions both in current scientific thinking and in the individual's own learning or development.

A classic question in psychology is to what extent the mind develops in a general as opposed to a specific fashion. Concern with domains and concern with theories reflect increased interest in the development of systems of cognition specific to some bodies of information and not others. This represents a contrast to several earlier domain-general approaches to cognitive development. For example, as it is generally understood (but see Chapman 1988), Piaget's standard theory describes general stages of thought (sensorimotor cognition, preoperational thought, concrete operational thought, and formal operational thought) that apply across widely varying content areas. For example, concrete-operational thinking similarly structures such disparate conceptions as the child's understanding of number, time, weight, morality, classification, and causality, or so the theory goes. In this sense Piagetian cognitive structures are content independent and also domain general.

Similarly, despite many contrasts with Piagetian theory, information processing views of development have, until recently, concerned themselves with general processes or architectures said to characterize cognitive development broadly. For example, the cognitive system's basic representational format was hypothesized to change with development from enactive, to iconic, to symbolic (Bruner 1964). Or, certain general parameters such as speed of processing or size of working memory were seen as increasing developmentally, and influencing all of cognition (Case 1985). Thus, studies of such basic information processes as storage and retrieval, for example, characterized memory development as a general improvement in capacity, strategies, and performance with age (see Kail & Hagen 1977).

The appeal of domain-general approaches is their ability to account for a broad range of phenomena with a relatively small set of principles. These approaches are thus parsimonious and powerful. However, in the last ten years or so a domain-general, content-independent picture of cognitive development has become increasingly problematic. At least some, and perhaps most, conceptual abilities seem specialized for, or first specifically developed for, particular types of contents. For example, memory skills and capacities were shown to be determined substantially by specific content and thus did not necessarily exhibit a developmental advantage for adults or older children over younger ones. In a seminal study of this sort (Chi 1978), children who were chess experts vastly outperformed adults who were chess novices on memory for chess board positions. This did not reflect better overall memory in these children, because the adults were better on standard memory tasks such as digit span—the classic developmental finding. Memory was not simply developing in some domain-general fashion but was tied, in part, to different contents, stemming from different domains of expertise.

Similarly, research on Piagetian topics such as classification and conservation seemed to show that the child "works out concepts in separate domains without using the kinds of integrative structures that would be required by a general stage theory" (Gelman & Baillargeon 1983:214). As Gelman & Baillargeon concluded in their review of the development of Piagetian concepts, this suggests "the possibility that there are domain-specific structures rather than domain-independent structures" (p. 210).

Although it is now widely acknowledged that domain-specific content has profound implications for human cognition, the term *domain* is used in several separable senses: 1. innately given, modular abilities, including for example a specialized faculty for language and language acquisition (Fodor 1983); 2. modes of processing tied to particular sensory modalities, such as verbal versus visual domains; 3. areas of knowledge that have special properties because of highly prolonged and intensive experience and expertise, including for example chess (Chase & Simon 1973); 4. Piaget-inspired partitionings of cognitive tasks such as the "domains of classification, seriation, and conservation" (Gelman & Baillargeon 1983:172); and 5. naive theories that carve phenomena into differing organized systems of knowledge and belief, such as biology (Carey 1985) or psychology (Wellman 1990). While these differing perspectives share a dissatisfaction with traditional views that cognition is domain general, they encompass distinctly different claims about domains: where they come from, what are prototypic examples, how many there would be, how they might be structured, and how and whether they would undergo developmental change. Innate modules, for example, can be assumed to be least open to change or individual variation; expert systems would be most open to change and variation (though they might be characterized more by learning than by development); and theories may entail a mixture of some unchanging core beliefs as well as a periphery of changing specifics.

Similarly, the term *theory* has been used to describe a great variety of specific conceptual understandings. These range from the very specific [e.g. a boy's assertion of a relation between eating sugary foods such as cake and catching colds (Kuhn 1989:676)] to global but still content-dependent bodies of knowledge [e.g. everyday understanding of biological phenomena such as life, death, digestion, and reproduction (Carey 1985)]. The term has been used to refer to concatenations of empirical generalizations—"a loose-knit network of largely tacit principles, platitudes, and paradigms which constitute a sort of folk theory" (Stitch 1983:1)—as well as to coherent, well-organized systems of explanatory beliefs (Murphy & Medin 1985).

We will not argue that any one usage is correct; current discussion points to several topics for further research and analysis. Instead, we examine a topic that lies at the intersection of a concern with theories and domains: the early development of foundational human knowledge systems. It has been proposed that infants and young children rapidly acquire certain bodies of knowledge that in turn frame or launch most later conceptual acquisitions. If this is so, then characterizing such conceptual structures would prove central to any understanding of domain-specific cognitive development. We concentrate on research that addresses this topic—a substantial portion of contemporary cognitive development research. Three features characterize this research and its theoretical significance: 1. a focus on knowledge (foundational human abilities could be content-free processes or architecture, such as memory buffers or rates of processing; in contrast the focus here is on bodies of knowledge that gain structure from the nature of their contents); 2. a focus on core understandings (some knowledge is more powerful, enabling, seminal, constituitive than other knowledge—knowledge of objects may be an apt example; how we understand physical objects figures in our understanding of measurement, astronomy, economics, geography, human artifacts, and so on); and 3. a focus on development (foundational knowledge constrains the path of conceptual acquisition, enabling learners to fill the gaps in underdetermined observations).

In what follows we sketch an emerging picture of several foundational knowledge systems. We begin with a brief presentation of a conceptual framework for construing some of the issues and for posing critical questions of the research; this revolves around the notion of framework theories that constitute domains of phenomena. Then we review research on what may well be three early-developing framework theories.

Framework Theories

A quick look at scientific theories shows that it is important to distinguish two different sorts of theories—foundational or framework theories vs specific theories. Specific theories are detailed scientific formulations about a delimited set of phenomena. To use psychological examples, theories at this level would include the Rescorla-Wagner theory of classical conditioning, Piaget's theory of object permanence, and Freud's theory of the Oedipal complex. On the other hand, there are also more global theoretical traditions. Examples in psychology include behaviorism, psychodynamics, and connectionism. Such framework theories constrain and guide the development of specific theories.

Philosophers of science have called framework theories paradigms (Kuhn 1962), research programs (Lakatos 1970), or research traditions (Laudan 1977). There are important differences in these writers' characterizations, but for our purposes there are basic commonalities. Specifically, framework theories outline the ontology and the basic causal devices for their specific theories, thereby defining a coherent form of reasoning about a particular set of phenomena.

> A research tradition provides a set of guidelines for the development of specific theories. Part of those guidelines constitute an ontology which specifies, in a general way, the types

> of fundamental entities which exist in the domain or domains within which the research tradition is embedded. The function of specific theories within the research tradition is to explain all the empirical problems in the domain by "reducing" them to the ontology of the research tradition. . . . Moreover, the research tradition outlines the different modes by which these entities can interact. Thus, Cartesian particles can only interact by contact, not by action-at-a-distance. Entities within a Marxist research tradition can only interact by virtue of the economic forces influencing them (Laudan 1977:79).

Framework theories define domains; they coherently parse phenomena into bodies of different specific contents. But such domains outline areas for discovery—that is, research programs—rather than finished bodies of understanding. Framework theories are, therefore, both open-ended and constraining; they allow and inspire the development of more specific theories but do so by defining the domain of inquiry in the first place.

This sort of analysis represents an attempt by philosophers of science to characterize an intriguing epistemological structure, framework understandings that predate and constitute, but at the same time are themselves further articulated in, more specific understandings of phenomena. Framework understandings of this sort could exist within individuals as well as in scientific communities, constituting areas of human thinking for further conceptual development. Indeed, in what follows, we review emerging research on the development of three possible commonsense framework theories: naive physics, naive psychology, and naive biology. A priori these seem to be three major sorts of understandings in that they encompass most of the external world with which we interact. When we consider that early humans were a distinctly social species evolved to use objects as tools and to hunt and forage within their natural environment, then it is hard to imagine any more fundamental cognitive tasks than knowing about people, about plants and animals, and about the physical world of objects.

Could these areas of thought even constitute foundational theories; could they represent everyday domains of thought organized around distinctive ontological categories and causal reasoning frameworks? Some sense that distinctive understandings may be involved can be seen by contrasting a material solid object (say, a billiard ball), an animate living organism (say, a butterfly), and a sentient human person (say, yourself). In our everyday thinking, these are three very different sorts of things engaging in very different forms of causal interactions. Consider the actions or movements of these three things. The ball moves if driven by some external force transmitted directly to it (e.g. another ball striking it), evidencing characteristic mechanical motion. The butterfly is self-propelled; it moves because of an inner biological "engine," evidencing characteristic biomechanical movements. A human engages in intentional action based on psychological reasons; the act of voting, for example, based on the belief that one candidate is best and on the desire to see him or her elected. Alternatively, consider three different human movements, as seen from the three contrasting perspectives: 1. physical forces—the wind buffets a human across the street; 2. biological forces—a human shivers in response to cold; 3. mental forces—the human imagines herself in a different place, decides to go, and persuades a friend to provide a ride.

These examples suggest the existence of three domains of reasoning constituted by three different ontological, causal-explanatory understandings; that is, three different naive foundational theories. Do humans develop such framework theories? If so, do they distinguish these three possible domains? And when: late in life as the product of many other developments, or early in development as the framework for further acquisitions? In what follows we assess contemporary cognitive development research that addresses these questions, we more precisely characterize the nature of these three kinds of knowledge, and begin to answer the questions of whether, when, and how they develop in childhood.

NAIVE PHYSICS

Partly because of Piaget's (1954) discussion of the object concept, students of cognitive development are accustomed to thinking of certain conceptions as providing a foundational framework for later cognitions. The object concept is an organism's knowledge that physical objects exist within a space encompassing self and object, but are independent of self in that they continue to exist when not in view. Imagine the worldview and actions of an organism without such an understanding, who instead "lives in an ever-changing world where objects are continually made and unmade" (Harris 1983:716).

An understanding of the existence of objects seems ontologically central to anything like our everyday physics— our ordinary understanding of the world of middle-sized objects and their interactions. Furthermore, everyday understanding of physical causality would seem to require some understanding of object dynamics—the force-transmissions that influence the position and movement of objects, for example that one ball colliding with another sets the second one rolling unless impeded. The two core framework notions here—physical objects and physical-mechanical causes—can become quite complex. After all, physical entities in the broadest sense encompass not only solid objects but unbounded masses like sand and snow, liquids like water, gases like air, and the insides of objects (the crystals inside a geode) as well as their material solidity; and physical causal-transformations include not only the dynamics of object contact but processes like flight, wave action, combustion, and melting.

Infants

Piaget (1954) concluded that the object concept was acquired late in infancy as an end-product of sensorimotor development. It was an insight based on, and manifest in, the infant's manipulation and practical experience with objects, especially searching for visible, then invisible, then invisibly moved objects. Recently these conclusions have been challenged because of Piaget's reliance on search tasks (e.g. Wellman 1986). Studies utilizing preferential-looking paradigms suggest a rather different developmental story.

For example, Baillargeon et al (1985) first habituated infants to a display of a rectangular screen, hinged at its base, that moved back and forth through a 180-degree arc—a "flapping panel." Infants viewed this display from the front, the panel flipping first forward and then away from them. After habituation, a box was positioned behind the panel, and infants were shown two test events, one a possible event and one an anomalous event. In the former, the panel swung to the front and then to the back, stopped appropriately when it touched the hidden box, and then swung forward again. In the anomalous case, it swung through the complete 180 degrees as if the hidden box were not there. Note that this anomalous event is superficially most similar to the habituation event, because in it the panel continues to flap through 180 degrees. Infants looked significantly longer at the anomalous (but similar) event than at the dissimilar but possible event. This suggests that infants were puzzled when the screen did not stop on expected contact with the box and thus believed the hidden box continued to exist. Baillargeon's many experiments (reviewed in Baillargeon 1992) contain a variety of converging controls and provide evidence that infants as young as 3–4 months represent the continued existence of an object that is currently invisible. The results also suggest that infants believe material objects to be solid and substantial (e.g. not simply compressed or scattered by the panel), and to remain stationary.

What about object dynamics? Infants' perception of physical causality has been the focus of recent research (Leslie 1982; Leslie & Keeble 1987; Oakes & Cohen 1990). As a specific example, Leslie showed 6-month-olds either (*a*) a film of one object colliding with and launching a second object, (*b*) or control events such as a first object making contact with a second one that only began to move after a considerable delay (violating temporal aspects of the causal dynamics). Leslie reasoned that since the control events do not specify causal connections, then an infant habituated to one of those events should be unsurprised if the event was reversed (since the reversal, too, provides no causal regularity). For the target event, however, reversal of the sequence specifies a real reversal of causal roles: The cause is now the effect. Thus, if infants understand the object dynamics, dishabituation should occur upon reversal only in the causally determined case. In several converging studies (reviewed in Leslie 1988), Leslie found dishabituation only upon reversing the causally proper sequence, suggesting an early appreciation of at least some aspects of mechanical causation.

Of course, infants could perceptually discriminate between causal and noncausal sequences without necessarily interpreting such events within a physical-causal understanding—that is, without representing physical causality conceptually (see Mandler 1988). Spelke has been especially concerned with the issue of whether infants' understanding of objects represents perceptual mechanisms or conceptual understandings, and with the timing involved (e.g. Spelke 1988). She argues that infants' understanding of physical objects and their spatiotemporal properties constitutes an early theory of objects, rather than merely a perceptual organization of current sensory experiences. Here she cites especially research like Baillargeon's above, demonstrating that infants' understanding of objects is apparent even in their reactions to invisible—not currently perceivable—objects. In her latest research (Spelke 1991), she extends such reasoning and methods to further investigate infants' understanding of object substantiality as well as object movements.

For example, in one study with 4-month-olds, infants were habituated to a sequence in which a ball fell behind a screen and then the screen was removed to show the ball at rest on the floor of the apparatus. Two test events then followed, in which an intermediate ledge was put in place behind the screen creating a shelf above the floor of the apparatus. In the plausible test event, the ball fell behind the screen, and when the screen was removed, the ball was on the shelf. In the anomalous test event, the ball fell, and when the screen was removed the ball was at rest below the shelf on the original floor of the apparatus. (This anomalous event, in which the ball somehow moves through the intervening shelf, was actually superficially most similar to the habituation event because the ball is seen at the same resting place when the screen is removed.) Four-month-olds looked considerably longer at the anomalous than the plausible test event. In this and further studies, Spelke showed that young infants expect invisible objects to continue at rest or motion, unless impeded by solid obstacles. At the same time, infants do not understand other ubiquitous physical events, such as the constant downward pull of gravity.

Later Developments

Little research exists characterizing the expanding understanding of objects in older infants and toddlers, but by age 3 or 4 years children evidence considerable understanding of physical objects and physical causality.

OBJECTS Not all understanding of objects involves their mere existence, solidity, and rigidity. As one recently researched aspect of this sort, consider children's understanding of the insides of objects. The insides of objects (the gears of a watch, the crystals within a geode) comprise the matter lying interior to the outer surfaces. Insides are often unobserved (though in principle observable), and they are often particularly important for understanding and explaining what items are and how they function (e.g. the gears of a watch vs its glass crystal). More generally, as adults we appeal to a variety of less obvious theoretical constructs to explain and make sense of the physical world—for example, an object's center of balance, mass, or its molecular composition—and insides may constitute an early analog for other theoretical constructs.

Recent work demonstrates that children know a significant amount about the insides of familiar objects by age 3 years. If asked to report the contents of various objects, 3-year-olds offer different answers for animate and inanimate things, typically reporting that animates have blood, bones, and internal organs (such as hearts or muscles), whereas inanimates have either nothing or have material such as cotton, paper, hair, or "hard stuff" (Gelman 1987). By age 4 years, children seem ready to assume that members of a particular category are likely to have the same internal parts and substance as one another, claiming, for example, that all dogs have "the same kinds of stuff inside" (Gelman & O'Reilly 1988).

These kinds of responses may represent nothing more than reports of common associates—responding "skin" or "shell" to questions about outsides and "stuffing"or "blood" to questions about insides, or reporting that since all watches are similar, their insides are similar. However, in a different sort of task, we asked chidlren to reason about triads of objects such as an almond, a very similar-looking rock, and a dissimilar-looking peanut (Gelman & Wellman 1991). Children were asked which two items looked most alike and which had the same kinds of insides. To answer correctly about insides, children had to select two items that looked very different on the outside. Even 3-year-olds were significantly correct at distinguishing insides and outsides. In a second study 4- and 5-year-olds judged that nonobvious insides were often essential to an object's identity or function. If asked, for example, would an egg still be an egg, or a turtle still a turtle, if its outside (shell) vs insides (white and yolk, or blood and bones) were removed, 4- and 5-year-olds affirmed that insides were more essential than outsides.

Objects such as eggs have distinct insides; in contrast a rubber ball is one kind of material throughout. Smith et al (1985) showed that even 4-year-olds understand that objects of this sort are composed of material substances and that such material kinds are different from object kinds. For example, they showed several items (e.g. a paper cup, a wooden airplane) to 4-, 5- 7-, and 9-year-olds who judged what they were and what they were made of. Then the items were cut into small pieces as the children watched and the child was asked whether it was still the same kind of object and whether it was still the same kind of stuff. At all ages children knew that the cut-up bits were no longer the same kinds of objects but that they were the same material kinds (e.g. still paper but not still a cup). Thus, at this age children already evidence a conception of matter in the sense of the kinds of materials out of which physical objects are composed. Additional research by Carey (1991) and her colleagues shows several ways in which children's conception of matter and object substances significantly develop beyond the preschool years. For example, preschool children judge that visible large pieces of Styrofoam, or very small but obvious objects such as a single grain of rice, weigh nothing at all. Thus having weight, having matter, and occupying space are not coextensive aspects of objects for young children, as they are for adults.

CAUSALITY One can think of causality either (*a*) as entrenched in different domains of content (the physical causes of object movements vs the psychological causes of human actions) or (*b*) as requiring only content-independent logical reasoning. Following Hume, for example, a causal inference might be induced whenever events (of whatever sort) exhibit requisite patterns of temporal and spatial contiguity and covariation. Developmental research on children's understanding of causality, following Piaget, began by documenting children's developing ability to make logical causal inferences in cases of isolated covariation. One conclusion of such research concerned preschoolers' consistent failures to reason causally in these logical ways (see Shultz & Kestenbaum 1985). In the 1980s, however, researchers questioned this conclusion, sensing that a Humean analysis missed an essential content-dependent aspect of human thinking about physical causal events, namely that we ordinarily assume and reason about specific causal mechanisms (Bullock et al 1982; Shultz 1982). In physical systems in particular we reason to and from assessment of specific mechanisms whereby some cause produces some effect by transmitting a force or restraint to it, or some set of forces causes trajectories, accelerations, and so on. Young children evidence several proficiencies at understanding the transmission and outcome of mechanical forces of this sort.

For example, a recent literature has tackled adults' and older children's understanding of naive physics by examining their understanding of classical mechanics (see Proffitt et al 1990). In these studies, people must predict, for example, the trajectories of balls rolling out of curved tubes or the weight or direction of movement of colliding balls. These studies show that adults' naive understanding of such motions is coherent, indeed theoretical (McCloskey 1983), although not always accurate with respect to scientific physics. Proffitt & Kaiser, who have contributed extensively to this literature, conclude that adults and children are relatively competent with "simple" problems as opposed to "extended body" problems to be discussed next— that is, problems where motions and force transmission involve essentially simple symmetrical objects whose action can be adequately seen in terms of a single particle of mass.

> We take this to be the case for four reasons. First, whereas early studies highlighted the tendency of college student populations to err on these problems, we note that typically the majority of subjects give correct responses. Second, when asked to reason about these problems in a familiar context, very few people make erroneous predictions (Kaiser, McCloskey & Proffitt 1986). Third, and of special significance, people demonstrate an excellent appreciation of particle dynamics when making judgments about ongoing events (Kaiser, Proffitt, & Anderson 1985; Kaiser & Proffitt 1986). . . . Finally, it should be noted that the events used in the intuitive mechanics studies are fairly complex exemplars of particle motions: external forces are applied and removed. The only experiments that have involved simple particle motions were developmental studies in which simple motions were used to ensure that young children understood the task (Kaiser et al 1986). Here, it has been found that even a child of 4 years of age realizes that a ball exiting a straight tube rolls straight, and a dropped object falls straight down (Proffitt et al 1990:347).

However, what Proffitt et al (1990) call extended body problems—problems that require an understanding of more than point masses—are typically poorly understood even by adults. By studying peoples' understanding of the dynamics of wheels, where, for example, both a center of gravity and a distribution of mass or a set of rotational forces are involved, they show that even very familiar events (such as rotating wheels) whose understanding falls outside the core notions of our intuitive physics may be completely misunderstood.

Perhaps children merely "see" or recognize familiar kinds of physical sequences of simple events. What of children's ability to reason inferentially about physical causality? Hume seems at least partly right: Understanding causality requires the ability to infer effects or causes from properly structured causal information. If knowledge about physical objects and physical causal mechanisms constitutes a domain of understanding, and if children are early acquiring a rich understanding of that domain, then they might evidence abilities to make appropriate logical inferences in that domain, although not more generally. Bullock et al (1982) tackled this question in a series of experiments with the following domino-like device. A stuffed rabbit sat on a platform. A series of domino-like blocks were lined up in front of the platform such that if the first block fell over it caused the others to topple over in series, and when the last block fell over it caused the rabbit to tumble from its platform. A device with a rod through a hole preceded the first block; when the rod was pushed through the hole it toppled the first block. In one study, 3- and 4-year-olds first saw the toppling sequence and then were asked to predict the as-yet-unviewed effect of 23 different relevant or irrelevant modifications to the device. Relevant changes included using a rod too short to hit the first block, and removing intermediate blocks. Irrelevant modifications included changing the material of the initial rod (from wood to glass) or wrapping a cloth around an intermediate block. Three-year-olds' predictions ranged from 78–91% correct, 4-year-olds' from 70–100% correct. This, and similar research by Shultz et al (1982) with a very different design, demonstrates young children's ability to reason correctly about physical causation mediated by a series of connected mechanical steps.

Shultz (1982) has demonstrated that by preschool age children reason sensibly not only about mechanically mediated causal sequences but also about immediate causal results, for several sorts of causal transmissions. In several ingeniously controlled situations, preschoolers attributed the snuffing out of a candle to a blower that was on rather than to one that was off, or the appearance of a spot of light to a lamp that was on as opposed to one that was off. The spotlight effect, for example, was instantaneous, not temporally prior, and involved no mechanical-spatial contiguity. Shultz thus demonstrated that young children are busily figuring out specific causal mechanisms and often reasoning properly about them, not noticing (or failing to notice) raw patterns of temporal sequence and covariation and deducing causes for them.

Finally, Goswami & Brown (1989) considered the possibility that when it comes to physical causality young children (3–6 years) might be able to engage in very sophisticated reasoning indeed—specifically, analogical reasoning. Piagetian theory suggests that analogical reasoning of the classical $a : b :: c : d$ form is very difficult for children before the age of formal operations, and considerable research supports the claim that such reasoning becomes apparent only late in middle childhood (Goswami 1991). However, the analogies used in these studies rely on relations such as semantic opposites (black : white : : hard : ?) or biological habitat (bird : air : : fish : ?). What if children's analogical reasoning were tested instead using physical causal mechanisms that they understand? Goswami & Brown first tested 3- to 6-year-olds' understanding of such familiar causal acts or transformations as cutting (a knife cutting bread) or melting. Causal reasoning about such transformations was typically very good, even for 3-year-olds; they knew, for example, that a knife cutting through a whole loaf of bread yields cut-up bread. Then Goswami & Brown tested children's ability to reason analogically about such relations via analogies such as, Playdoh : cut-up Playdoh : : apple : ?. After being presented the first three terms in this problem, children had to choose the correct answer for the missing last term of the analogy from several carefully composed alternatives: 1. a correct choice (cut-up apple); 2. a correct object but wrong physical change (bruised apple); 3. a wrong object but correct physical change (cut-up bread); 4. a mere appearance match for the third term (red ball); 5. a semantic associate of the third term (banana). Even 3-year-olds' analogical reasoning was significantly correct for these sorts of problems. Goswami & Brown conclude that "as long as the child understands the causal relation, he or she can solve an analogy based on that relation" (1989:79).

Conclusions

Understanding physical objects and understanding physical causes are complex endeavors: Witness the complexity of scientific physics. Still, an understanding of solid objects and mechanical dynamics seems central to understanding physics more generally. Indeed, certain core beliefs about the nature and causal interactions of the everyday world of physical objects seems a domain of early foundational human knowledge and reasoning. A developing naive physics makes its early appearance in an infant's understanding of solid, cohesive, physical objects and certain causal regularities among them. The infant's understanding becomes rapidly enriched to include a deeper understanding of objects (for example their insides) and of physical causality (for example, object dynamics and causal mechanisms).

In order to claim that young children have a naive physics, however, we need to ask if the understandings we have reviewed function as a distinct domain for children. Specifically, is this sort of knowledge and reasoning separable from other domains of knowledge? We address this question in the next section where we describe a potential alternate domain, naive psychology. We ask, first, do children make a fundamental ontological distinction between the two domains—for example between physical objects (e.g. rocks) and psychological entities (e.g. thoughts about rocks); and, second, do children distinguish and reason differently about mechanical and psychological causation?

NAIVE PSYCHOLOGY

As outlined earlier, persons may be construed in several ways. Here are two: as physical objects (material bodies) mechanically interacting with other physical bodies, or as psychological beings whose actions are caused and explained by psychological forces and states. Adult naive psychology adheres to this second sort of construction. We construe people's actions as resulting from such internal mental states as their hopes, wishes, beliefs, and doubts. If any two domains of thought could be considered distinct, mentality and mechanics could.

What characterizes naive mentalistic psychology? Consider two of its central components: the ontological and causal aspects of mind. The ontological aspect concerns the existence and nature of mental contents, states, and processes as and distinguished from the real world of physical objects, material states, and mechanical or behavioral processes. Contents and states of the mind are internal, mental, and subjective, whereas the contents and states of the world are external, substantial, and objective.

Thoughts, beliefs, and ideas are distinct from the physical world of objects and behavior, but they are causally related to that physical-behavioral world. Mind causes action; the world shapes mind. A useful shorthand for characterizing psychlogical causation is to divide causal mental states into two sorts: beliefs and desires. Causal reasoning based on beliefs and desires then produces such accounts as the following: *Why did Jill go to that restaurant? She* wanted *to eat quickly and* thought *that it was a fast-food place*. Thus an essential causal idea is that people engage in actions because they believe those actions will fulfill certain desires. Under the heading of "theory of mind," recent research has documented the emergence of our everyday understanding of such mental states and reasoning.

Theory of Mind

Current research reveals sophisticated reasoning about the mental states of self and others in 3- to 5-year-olds. This contemporary consensus overthrows earlier assertions that young children were ignorant about the mind, misconstruing internal mental states and contents as external physical ones until 6 or 7 years of age (e.g. Piaget 1929; Keil 1979). We begin by considering 3- and 4-year-olds and then move backwards to infancy.

ONTOLOGY Children as young as 3 years firmly distinguish the mental and physical worlds. For example, if told about one boy who has a dog and another one who is thinking about a dog, they correctly judge which "dog" can be seen, touched, and petted, and which not (Harris et al 1991; Wellman & Estes 1986). Moreover, if told about someone who has a dog that has run away and about someone who is thinking of a dog, 3-year-olds know that although neither "dog" can be seen or petted, one is mental ("just in his mind," "only imagination") whereas the other is physically real but unavailable (Estes et al 1989). By 3 years children know that physical force is necessary to manipulate physical objects (e.g. to open and close a real pair of scissors) but that "just thinking" is sufficient to affect mental changes (e.g. to open and close the image of a pair of scissors in your mind) (Estes et al 1989).

Young children also understand something of the subjectivity of thoughts. In appropriately simple tasks they are able to state, for example, that they can "see" their own mental images but that others cannot (Estes et al 1989), or that while they think a particular cookie tastes yummy, someone else could think it's yucky (Flavell et al 1990).

BELIEF What about the causal aspect of mind? Investigators have studied extensively what young children understand about the beliefs of other persons and what they know about how beliefs guide behavior. Beliefs are central to our everyday grasp both of the way the mind influences action (*Jane takes her umbrella because she believes it is raining*) and of the way the mind reflects the world (*Jane believes it is raining because she saw rain outside*). To understand mental causation children must recognize that people behave in response to their beliefs about the world, not in response to "objective" facts. For this reason, children's understanding of false beliefs (*Jane believes it is raining, but it is not*) provides especially intriguing and useful evidence about how they understand causal mental states more generally. Many studies now show that by 4 years children reason proficiently about false beliefs (see e.g. Perner et al 1987). For example, if shown a candy box they will predict it contains candy. If then shown it holds pencils, they can correctly predict that a naive viewer of the box will falsely believe it contains candy instead (Gopnik & Astington 1988). Some studies show an even earlier understanding of belief in 3-year-olds via their understanding of true beliefs (Wellman & Bartsch 1988) and their use of common terms such as think and know (Shatz et al 1983). Indeed several recent studies show an initial understanding of false beliefs in 3-year-olds (Bartsch & Wellman 1989; Siegal & Beattie 1992; Lewis & Osbourne 1990; Moses 1990; Hala et al 1991; Wellman & Banerjee 1991).

The status of 3-year-olds' understanding of belief and false belief remains controversial. But a substantial consensus remains wherein 4-year-olds, if not 3-year-olds, are characterized as belief-desire reasoners. Indeed by 4 years, normal children's understanding of the mental mediation of experience and behavior is robust enough that they understand the existence not only of false beliefs but also of false perceptions (Flavell et al 1986).

COHERENCE As discussed above, by age 3 children seem to recognize a domain of mental-psychological entities and processes distinct from a contrasting domain of physical objects and mechanical processes. To count as a framework theory, however, more is needed: some degree of coherence among children's beliefs. "Not any collection of beliefs forms a theory. The unity of a theory . . . is something that most sets of assertions cannot have. Number all the commonly held beliefs, and take the theory consisting of the prime numbered ones. . . It couldn't evolve as a unit or be criticized as one" (Morton 1980:6).

It may be impossible to tackle the question of coherence in the abstract, to specify the sort of coherence required for all theories. However, it is possible to assess whether children grasp the sort of coherence entailed by a particular theory; as for example our everyday mentalistic naive psychology. Briefly, according to this everyday theory, physiological states and basic emotions underlie one's desires. Beliefs, on the other hand, are often derived from perceptual experiences. Moreover, one's actions lead to outcomes in the world, and these outcomes lead to emotional reactions of predictable sorts, such as disappointment, happiness, and surprise. Thus various constructs within a naive psychology make reference to one another. Accounts of coherent everyday belief-desire reasoning are elaborated more fully by D'Andrade (1987) and Wellman (1990:Ch. 4).

By 3 or 4 years of age young children demonstrate that they understand this larger interelated system of constructs and reasoning. Recent research shows that young children can reason forward from beliefs and desires to predict a person's actions (e.g. Wimmer & Perner 1983; Wellman & Bartsch 1988). They can also reason backwards (Bartsch & Wellman 1989): If asked about an action (*Why is Jane looking under the piano for her kitten?*) they explain it by appeal to beliefs (*She thought it was there.*) and desires (*She wanted her kitty.*).

By age 4 or 5 children understand that perception is instrumental in the acquisition of beliefs (Wimmer et al 1988; Taylor 1988). Again, recent studies suggest that some initial understanding of the links between perception and belief are understood in significant initial forms by 3- as well as 4- and 5-year-olds (Pillow 1989; Pratt & Bryant 1990).

According to our everyday theory, emotions are also entangled in this web of causal mental states. Some emotional reactions, for example, depend predominantly on the person's desire, others on the person's beliefs. If an actor desires something and then gets it (or fails to get it) he is likely to feel happy (or sad or mad). If he believes something will happen but it does not, he is likely to feel surprise or puzzlement. The causal understanding of emotional events is, in this fashion, mentalistically dependent not just on situations but on beliefs and desires (Stein & Levine 1987). By 3 years, preschoolers seem to understand the causal organization of emotions such as happiness, sadness, and anger (Stein & Levine 1989; Yuil 1984). Indeed even 2-year-olds begin to do so (Wellman & Woolley 1990). More recent research on children's understanding of surprise shows that preschoolers' organization of emotional understanding encompasses belief as well as desire states, although there is controversy about whether understanding of surprise appears at about 3 years with the first understanding of belief (Wellman & Banerjee 1991) or later, in the preschool years (Hadwin & Perner 1991).

By age 3 or 4, it can be argued, children's naive psychology evidences the character of a naive framework theory with a content and coherence that is quite different from that of a contrasting naive physics.

Earlier Developments

Where might the mentalistic framework psychology of 3- and 4-year-olds come from? A plausible hypothesis is that it is related to, although importantly distinct from, infant social discriminations. Even in the first months of life, infants are complex social creatures. They cry, smile, attend to faces, imitate others, become attached, and interact in dyadic face-to-face routines. If framework theories are manifest in (*a*) an ontological aspect that picks out certain entities for consideration and (*b*) a causal aspect that frames explanations about how such entities interact, then infant social understanding could encompass two parallel precursory aspects—mechanisms for picking out social objects for special processing, and early discrimination of human movements and causation.

The young infant seems to be specially prepared to attend to and interact with social objects. Infants preferentially attend to faces (or, at first, arrays with face-like configurations and features) (Sherrod 1981); they discriminate facial expression of emotion at an early age (Nelson 1987); and they imitate human actions (Meltzoff & Moore 1983). Infants find bodily contact with and being held by others desirable, and they seek out such contacts with the onset of voluntary movement. Infants attend preferentially to human speech over other sounds—especially female speech and even specifically their own mother's voice (DeCasper & Fifer 1980). Theories and research on parent-infant attachment (e.g. Bowlby 1969) and interaction (e.g. Stern 1985) amply document certain proclivities that help infants attend to and represent people as special, significant, and information laden.

Similarly, there is evidence of early infant attention to human movement. Young infants discriminate animate-biological motions vs random or artificial ones (Bertenthal et al 1985), and older infants (by 13 to 16 months, for example) seem able to distinguish between (*a*) the sorts of internally generated and self-propelled movements possible to people and (*b*) the transmission of external forces necessary for movement of physical objects such as balls and rocks (Poulin-Dubois & Shultz 1988; Golinkoff 1983). Indeed, Premack (1990) has recently argued that infants probably evidence a rich biologically prepared tendency to discriminate animate self-propelled movements in contrast to inanimate externally caused physical ones. However, it is important to point out that while preference for faces and attention to self-propelled motions may lead the infant to study human conspecifics, such competencies do not indicate a specifically mentalistic psychological understanding of any sort.

A conception of mental states and mentally caused actions requires something more. A critical step in this direction would be something like an understanding of intentionality, as philosophers use that term (not intentional in the narrower everyday sense of "on purpose"). The hallmark of intentionality in this sense, is "aboutness," or object-directedness. Consider a desire for an apple or a belief that something is an apple; such desires and beliefs are object specific; they are *about* an apple. Attributing intentionality therefore requires attributing internal states (or attitudes) directed toward (or about) specific objects (or contents). Many who study infancy describe a transition in infant social interaction first evident in the period from 9 to 12 months wherein the infant seems to see self and others in notably different terms. This change has been termed the advent of a sense of subjectivity (Stern 1985), triadic awareness (Adamson & Bakeman 1985), and even an implicit theory of mind (Bretherton et al 1981). It can be argued that the older infant manifests a transition to understanding people (self and others) as intentional in the very rudimentary but significant sense of having certain experiences *about* or *of* external objects or events (Wellman, in press).

Consider, for example, early understanding of others' perception or attention. Gestures such as pointing and showing emerge between 9 and 13 months or so (Butterworth 1991; Lempers et al 1977; Zinober & Martlew 1985). Some early sorts of pointing could be simple actions of the infant toward the object itself (something like attenuated poking or reaching). But research consistently documents pointing and showing in the child's second year directed at getting others to attend *to something*. For example, if the other's eyes are covered by his or her hands, 1.5- and 2-year-olds will move the hands or try to place a to-be-shown object between the hands and eyes (Lempers et al 1977). In the second year the infant points at an object but also in increasingly sophisticated ways looks at the other to check that person's gaze as well (Masur 1983). In compelling cases the infant will begin to point only when the other is attending to him or her, execute the point, check the other's visage, keep pointing or augment the behavior if the other is not correctly directed, and quit if the other orients or comments on the object (Bates et al 1979; Butterworth 1991). Findings such as these document a simple intentional understanding of perception, that people can be perceptually directed toward certain objects or events.

An understanding of intentionality must go beyond an understanding of reference, however; it must include an understanding of internal psychological experiences. Research on social referencing in infants suggests that in the second year infants know not only that persons are oriented to objects in the world, but also that they experience them—e.g. as pleasing or scary, desired or undesired (Walden & Ogan 1988). Of course, simple attention or even reaction to others' emotional displays would not necessarily imply an intentional understanding. Referencing a mother's frown or smile could simply and directly alter the baby's mood (Feinman 1985) or action (perhaps the infant sees the mother's fear expression and simply freezes). However, social referencing could work through the infant's reading the other's emotional expression as indicating an emotional reaction about a particular situation or object. Indeed, Hornick et al (1987) seem to have demonstrated this sort of intentional understanding by 1-year-olds. In that research, mothers posed expressions of delight or disgust toward a particular toy in a situation containing several alternative toys. The 12-month-olds in that study were selective in reaction, interpreting mother's expression as about a particular toy. For example, they avoided a toy toward which the mother expressed disgust but showed no change in overall mood and approached and played with other nontarget toys.

Note that while understanding people as having certain inner experiences (happiness, fear) of external objects, actions, or situations qualifies as an impressive understanding of intentionality, it does not mean that children construe people as having all the sorts of inner experiences encompassed by belief-desire understanding. In particular, a simple understanding of intentionality does not encompass internal *representations* of the world, such as images or beliefs. In this regard, consider that simple desires can be construed as an internal experience (or longing) for external objects (he wants that apple). Beliefs, however, require an understanding of mental representations (he thinks that that is an apple). Thus it is of import that 2.5-year-olds understand simple desires but fail to understand comparable beliefs (Wellman & Woolley 1990).

To summarize, by age 3 or 4, young children see people as possessing beliefs as well as desires; as having ideas, thoughts, and images as well as emotional reactions. This achievement of a belief-desire understanding is preceded by earlier phases. There is a phase of infant attention to people as entities and to personal-human causation as different from physical-mechanical causation. More important, with regard to specifically psychological conceptions there is a phase evident at least in later infancy of simple intentional understanding of action and experience, evident in construing people as gazing at, seeking to attain, and emotionally reacting to real-world objects and actions. This constitutes first evidence of a rapidly developing understanding of people as having the intentional subjective experiences of seeing, desiring, and emotionally experiencing the world.

Autism

If a mentalistic construction of persons constitutes a distinct domain of human thinking, then it may be possible to find people who evidence distinctive impairment of this sort of reasoning. Recently, researchers have proposed that autistic persons lack a "theory of mind" or are severely delayed or impaired in everyday mentalistic psychology (Baron-Cohen et al 1985). A provocative initial case has been made: Autistics can reason about physical causation but are impaired specifically with regard to understanding mental causation, even in comparison to retarded controls of the same mental age (see Baron-Cohen 1990 for a review). These data suggest that mentalistic naive psychology may well be a distinct domain of human thought.

Conclusions

Our discussion is by no means a complete summary of children's understanding of naive psychology. Naive psychology includes or overlaps with children's understanding of moral issues, kinship relations, social roles, and so on. Many of these topics are currently receiving vigorous research. For example, there is an extensive current literature on preschool and school age children's understanding of emotion (see Harris 1989) and of personality traits (see Rholes et al 1990). Such research falls under the heading of social cognition and social cognitive development. The research we have reviewed can be seen as attempting to base social cognition in a mentalistic belief-desire psychology. The foundational core of this domain seems to be understood and used by children quite early in development.

NAIVE BIOLOGY

Everyday notions of biology encompass such processes as organic growth, reproduction, and inheritance; such animal functions as eating and sleeping; and such outcomes as illness and death. The study of biology enables us to see the important commonalities between humans and other species (including plants), as well as the critical ways that species differ in their solutions to important evolutionary problems. Indeed, we humans have been fascinated by our relationship to other species, sometimes viewing ourselves as part of the animal and natural world, sometimes as standing apart from it (Thomas 1983).

Do children show evidence of a framework biological understanding distinct from naive physics and psychology? There are at least two plausible ways in which they may not. First, biology could be confused in children's minds with psychology (internal motivations, feelings, beliefs on the one hand; beliefs about human social interaction on the other). Particularly given the power of psychological causes, detailed above, children may explain biological processes in terms of psychological ones (people grow because they want to get bigger) as hypothesized by Carey (1985). Second, biology could also fail to function as a distinct domain if domain-general principles govern children's understandings. For example, children may classify animals and plants using domain-general principles of similarity (e.g. classifying objects by overall color and shape), failing to attend to any specifically biological features (e.g. presence of eyes, particular types of limbs, blowholes). This possiblity has been explicitly articulated by Keil (1989) and by Gelman & Coley (1991).

Again these issues require us to address, first, whether children have a sensible, separate ontology of biological kinds, and second, whether children hold beliefs about distinctly biological causal laws and principles. If we can establish that children refer to specifically biological ontologies and laws, then we must also consider coherence: whether these laws or principles are theoretically organized with respect to one another. We argue that children have at least the outline for a biological theory by preschool age.

Ontology: Living Things

ANIMATE/INANIMATE DISTINCTION Piaget's (1930) account of animism would argue against children's making a clear ontological distinction between biological and nonbiological kinds of objects. On this account, children attribute animate properties to inanimate objects (e.g. a bicycle is alive; rocks can feel pain). The evidence, typically based on the clinical interview method, suggested that until school age children were not at all clear on the distinction between animals (e.g. elephants, fish, insects) and inanimate objects (e.g. desks, houses, pencils).

In contrast, a rich body of research using more sensitive measures demonstrates that young children make a firm ontological distinction between animate and inanimate objects. This distinction does not map directly onto the biological/nonbiological distinction (because although plants are alive, since they cannot move on their own, children consider them inanimate). Nonetheless, the animate/inanimate distinction may be the beginning of the grasp of biological kinds as a distinct domain.

Golinkoff et al (1984) review a variety of evidence that children distinguish animate and inanimate in their language comprehension and production (e.g. in their early production of sentences, most syntactic subjects are animate; see Brown 1973). Golinkoff & Markessini (1980) devised a simple pointing task in which children were asked to respond to various possessor-possessed relations. When the questions involved an animate possessor ("Where's the boy's flower?"), children performed quite well; in contrast, they often refused to answer when the possessor was "inanimate" ("Where's the flower's boy?"). Golinkoff et al (1984) found that by 24 months of age children typically show surprise when a chair moves forward on its own. By that age they are therefore sensitive to one of the most important criteria distinguishing animate from inanimate objects (capacity for self-generated movement).

Gelman & Spelke (1981) map out a variety of criteria that children could use to distinguish animate and inanimate objects (e.g. capacity to grow; capacity to move and initiate actions without external force) and suggest that this distinction may be among the first that children honor. Gelman et al (1983) argue that Piaget's methods biased children toward supplying animistic answers. In their own tasks, involving simple yes/no questions about actions, parts, and states (e.g. "Can a person (rock, doll) feel sad?"), they find that children as young as age 3 clearly distinguish animate from inanimate items (e.g. animates but not inanimates have feelings and autonomous movement, and can reciprocate actions; see also Dolgin & Behrend 1984 for related findings). With slightly older children, Keil finds that children distinguish animals from inanimate objects, for example, reporting that a porcupine cannot be transformed into a cactus (1989) and that the predicates that apply to animals do not apply to inanimates (1979).

Clearly, then, even young children honor a distinction between animate and inanimate. Are they using domain-general principles on which to do so (e.g. a simple similarity metric)? Apparently not. According to Carey (1985), children report that a mechanical monkey is highly similar to a person but unlikely to have properties attributed to people (e.g. eating, sleeping, having babies). Thus, children distinguish animates from inanimates in ways that cannot be reduced to domain-general principles of similarity. In a more in-depth look at this question, Massey & Gelman (1988) found that preschool children can classify unfamiliar animate and inanimate objects on the basis of very subtle cues. For example, highly realistic statues of animals were grouped with other inanimates (i.e. were judged to be unable to move up a hill by themselves); highly atypical animals (e.g. porcupines) were grouped with other animals.

Similarly, a recent study by Jones et al (1992) showed that young children extended novel labels (e.g. "dax") differently depending on whether the objects being named had eyes or not. Apparently, the information that something is an animal (conveyed by the presence of eyes) led to a shift in the properties children attended to. These studies demonstrate that a simple notion of domain-general similarity cannot account for the animate-inanimate distinction children make.

INFANCY The data so far available from infants suggest that babies are specially attuned to humans and other animals—i.e. are particularly interested in faces and eyes, respond to emotional expression in faces from an early age, and attempt to communicate with other humans and not with inanimate objects. Although not constituting an appreciation for the biological domain per se, this argues against a domain-general understanding of the biological world.

Some recent evidence suggests that infants distinguish animates more generally from inanimates. In a habituation study with 12-month-old infants, Smith (1989) found that subjects treated toy versions of artifacts and animals as falling into separate classes. Infants saw a series of toy objects of one type (e.g. all animals) until their attention waned. They then saw a new toy object, either of the same ontological type (e.g. another animal: an elephant) or of a different ontological type (a toy vehicle: a boat). Of interest was how long children gazed at the new object. Children's attention increased when the novel object was of a different ontological category (e.g. when the experiment switched from artifacts to an animal or vice versa). Moreover, this discrimination could not be attributed to the mere presence of distinguishing parts such as eyes and mouths (for animals) vs wheels and windshields (for vehicles).

CLASSIFICATION OF PLANTS The above evidence supports the view that children are not animistic, and that they honor an ontological distinction between animate and inanimate objects—perhaps even in infancy. However, this distinction might be rooted in an understanding of psychology rather than of biology per se. That is, children might distinguish animals from inert physical objects on the basis of motivations and mental states that animals such as humans (but not other biological beings, such as plants) could have. Thus, an intriguing issue is how children classify plants, which fall within the domain of biology but not psychology.

Carey (1985) finds that children below age 10 show confusion about what it means to be "alive" (see also Piaget 1929; Laurendeau & Pinard 1962). The confusion arises, she argues, from their not understanding how animals and plants can be grouped together to form a coherent category. Richards & Siegler (1984, 1986) find that plants are rarely classed as "alive" until age 8 or 9 (see Stavy & Wax 1989 for errors continuing till age 12). Clearly this is an area of important developmental change. However, by themselves these findings do not address directly the question of whether children conceive of a distinctively biological domain. Children may simply not understand that the biological domain, for adults, includes plants. The question is better addressed by looking more closely at children's beliefs about biological kinds.

Beliefs about Biological Kinds

ATTRIBUTION OF PROPERTIES In an extensive series of studies, Carey (1985) demonstrates that how children attribute properties (e.g. eating, sleeping, breathing, having babies) to other animals reflects not an adult-like biological model but the approximation of those animals to humans. That is, living things are not seen as categorically alike in having biological functions—not even all animals are assumed to require food, air, and sleep—but are graded in terms of their similarity to humans. Moreover, when taught new properties about a novel living thing (e.g. that a certain animal has "golgi" inside), children generalize the property only to other animals (again, using humans as the prototypical haver-of-things) and not to plants. And when supplied with two examples of things that have the new property—examples that for adults would span the category "living thing" (e.g. dogs and flowers)—children are prone subsequently to generalize the property to inanimate objects (implying that they see nothing common to dogs and flowers aside from being physical objects).

Carey uses these findings to argue that children do not have a theory of biology, and that they understand what for adults are biological functions in terms of anthropocentric psychological principles. However the evidence is quite indirect. Again, children may indeed treat biology as a distinct domain but fail to grasp either the scope of the domain (excluding plants, for example) or how it is organized (e.g. that vertebrates form a subclass within animals) for adults.

With a more direct examination of the issue, Inagaki & Hatano (1988; Inagaki 1990) have challenged the view that psychology and biology are inseparable for young children. They have asked whether children realize that psychological laws operate independently of biological laws and vice versa. In one study, they presented 4- and 5-year-old children with three different kinds of tasks: differentiation, controllability, and conflict. Differentiation tested whether children could distinguish among hereditary, bodily, and mental characteristics with respect to their modifiability (e.g. *Could a boy change his eye color if he wants to?*). Children reported distinctly different means of modifying mental vs bodily characteristics (e.g. intentions vs physical practice, respectively). Controllabilty measured whether children believe that bodily functions can be controlled by intentions (e.g. *Can you stop your heartbeat?*). According to Inagaki & Hatano, "both 4- and 5-year-olds understand that there are things going on inside the body which are not fully subject to our intention" (1988:5).

Finally, the conflict task examined whether the children thought biological or intentional forces are more effective in modifying physiological features. For example, subjects were asked to predict who will become fatter, a girl who wants to get fat but who eats less or one who wants to get slim but eats more. If psychological laws dominate, then wanting to get fat should prevail. If psychological and biological laws are confused, then children should guess randomly. But if biological laws are understood as existing and potentially conflicting with psychological ones, then children should report that the first girl will not get fat. Indeed this is what 90% of the 4-year-olds and 95% of the 5-year-olds reported. Inagaki & Hatano point out that children of this age still do not understand in detail how biological processes (such as digestion) work, although appreciating biology as separate from psychology.

Gelman & Kremer (1991) similarly find that preschool children have a grasp of biological causation that does not involve human intention or human action (for example, children realize that leaves turn color because of intrinsic, innate forces rather than human ones). This is at least a step toward distinguishing biological from psychological cause. If children were restricted to thinking about psychological or mechanical causes, they should be unable to grasp the idea of nonhuman nonmechanical causation. Children also distinguish intended actions from reflexes by age 5 (Shultz et al 1980). Thus, they do not apply a psychological model of causation indiscriminately, even in cases that might easily be confused with such a model.

CONCEPTS OF IDENTITY The nature of identity—what properties make something the individual or category member that it is (e.g. what makes Joe a unique person, a male, or a mammal)—varies importantly as a function of domain (Schwartz 1977). Keil (1986, 1989) points out that, for adults, dramatic changes in appearance can affect the identity of artifacts but not of living kinds (e.g. alterations can change a coffeepot into a birdfeeder but cannot change a horse into a zebra). Children grasp this insight by second grade (Keil 1986, 1989). In contrast, according to Keil, kindergarten children fail to grasp the distinction, treating the identity of both living kinds and artifacts as changed. However, a possible source of their confusion at this younger age is that the transformations probed by Keil were nonnatural, for example, surgery.

For living kinds, both personal and species identities are maintained across the dramatic but nonetheless natural changes that occur with growth. Recently, Rosengren et al (in press) pointed out that adults have three conceptual insights about such natural changes (such as an egg hatching into a tadpole and becoming a frog). First, real-life transformations are predictable and nonrandom (e.g. animals can increase but not decrease in size, as they grow). Second, the kinds of transformations possible are domain and mechanism specific (e.g. growth applies to animals and plants but not chairs). Third, identity is maintained across even striking appearance changes, such as the transformation from infancy to adulthood. In a series of experiments, Rosengren et al demonstrated that children as young as age 3 years appreciate the first two insights about growth: They realize that animals increase (but do not decrease) in size as they mature and that growth does not apply to artifacts. (The third insight was not tested directly in these studies.) When judging natural but radical transformations children do not accept just any change as possible, nor do they assume that transformations necessarily lead to changed identities.

Gender identity is of specific interest in this context because it readily lends itself to being construed in multiple ways: as a social, psychological, or biological construct. Based on research on gender constancy (Kohlberg 1966; Liben & Signorella 1987), Carey (1985) suggests that children construe gender as a social construct. According to Carey, changes in social roles (e.g. change in behavior or play pattern) are enough to cause children to judge that sex has changed. However, the gender constancy task may not be an appropriately sensitive measure. Siegal & Robinson (1987) argue that the task itself is pragmatically odd and that minor modifications (e.g. reversing the order of the questions) result in vastly improved performance. Gelman et al (1986) also point out that the gender constancy task requires children to construct a gender classification on the basis of conflicting cues (e.g. when shown a child who used to be a boy but now looks like a girl). Even for adults, classifying ambiguous entities is difficult (cf Mayr 1988). In contrast, when children are explicitly given the gender identity of an ambiguous individual (e.g. they are told that a long-haired child is a boy), even 4-year-olds infer sex-appropriate properties about that child (e.g. he will play with trucks and grow up to be a daddy) (Gelman et al 1986). Finally, even 4-year-olds treat gender like a biological construct in the sense of having innate potential that is largely unaffected by environmental influences (Taylor & Gelman 1991; see also Smith & Russell 1984 with evidence from older children).

Biologically Specific Causal Processes

If naive biology functions as a separate domain of reasoning for children, they should understand something about biologically specific causal transformations—causal processes that dictate how and why characteristically biological events unfold. Maturational growth, as discussed above, is an example of exactly this sort. There are other important instances as well—e.g. inheritance, disease transmission and contagion, and biological potential. In each case what counts as an effective cause, and the consequence of that cause, cannot be translated into any other domain. For example, the laws of inheritance cannot apply to inanimate objects (40-watt light bulbs do not beget other light bulbs). Such specifically biological processes begin to pinpoint areas in which naive biology might approximate a coherent theory.

INHERITANCE AND INNATE POTENTIAL The concept of inheritance is specifically biological, in that only and all living things have mechanisms for transmitting features from one generation to the next. Most research on conceptions of inheritance focus on children with at least some schooling (Clough & Wood-Robinson 1985; Deadman & Kelly 1978; Kargbo et al 1980). In contrast, Springer & Keil (1989) recently examined models of inheritance in children as young as preschool age. Children heard stories about parent animals that possessed a certain abnormal feature (e.g. "Mr. and Mrs. Bull . . . were both born with pink hearts inside their chests instead of normal-colored hearts"). They were then asked to predict whether their offspring would be born with a normal form of the feature or an abnormal form (e.g. a normal-colored heart or an odd pink-colored one). Preschoolers were most likely to consider features as inherited when they had biological consequences (e.g. born with a white stomach inside so they could eat a lot and stay strong) rather than social or psychological consequences (e.g. born with a white stomach inside that made them feel angry a lot). As Springer & Keil report, "our subjects demonstrated a consistent, implicit belief that alterations leading to functional consequences for animals are inherited, while other sorts of alterations are not. . . . this belief is limited to biological rather than social or psychological consequences. This seems to implicate a biological theory of inheritance" (1989:647).

Closely related to the notion of inheritance is that of innate potential. In particular, biological entities—but not other kinds of objects—manifest predictable features that are dictated by their innate potential. For example, a newborn tiger is neither large nor fierce, yet it inevitably comes to exhibit those traits. Adult naive biological thinking accounts for these phenomena by considering them as part of an animal's innate potential. To test children's grasp of innate potential, we presented 4-year-olds with a series of stories describing a seed from a plant or a newborn animal that was reared with plants or animals of a different species (Gelman & Wellman 1991). For example, a newborn cow was taken to a pig farm and raised with other pigs, never seeing another cow. Children saw realistic pictures of the newborn (which did not resemble the adult form of its parents or foster parents) and of the rearing environment. They were then asked to judge what behaviors and physical attributes the plant or animal would manifest when grown to adulthood. For animals, both younger and older 4-year-olds consistently reported that the infants would grow to have the innate potential characteristic of their species (e.g. the baby cow will moo and have a straight tail, despite being raised with pigs). For plant seeds, older 4-year-olds showed the same pattern of response, although younger 4-year-olds were performing at chance levels. Thus, a specific belief about biology (a belief in innate potential) is found even in young 4-year-olds.

CONTAGION AND ILLNESS Contagion is an interesting belief to examine from the perspective of biological theory. In adult form, it is a domain-specific causal notion, in three senses. First, it provides a causal analysis of disease that applies to biological entities only: A car cannot "catch" a flat tire from another car. Second, only certain bodily illnesses are contagious—not accidental mishaps such as a bruised knee, nor even other bodily pains such as toothaches. Third, for adults in our culture illnesses are spread by biological means and cannot be explained by appeal to other causal domains (e.g. as the result of immanent justice, in which illness is the inevitable consequence of moral transgressions). Adult understanding of contagion is specific to the domain of biology. It would be easy, however, for children to construe contagion in a wholly domain-general manner, operating on the basis of domain-general principles such as contiguity and similarity. On this view, illness could be transmitted between any two things as long as they are near one another, or as long as they are similar. It would also be easy to construe contagion on psychological terms alone, as the immanent justice example demostrates.

Some intriguing studies in the literature have suggested that children at first understand contagion in terms of domain-general principles: A variety of illnesses or accidents—including toothaches or scraped knees, for example—are viewed as contagious (Kister & Patterson 1980; Piaget 1932). Kister & Patterson (1980) and Bibace & Walsh (1981) also found children adhering to immanent justice explanations—reporting, for example, that moral transgressions could be the cause of various ailments (a cold, a toothache, a scraped knee).

Using a simpler task, however, Siegal (1988) has found that preschool children evidence more knowledge about contagion and contamination than previously suspected. Children were asked to evaluate explanations provided by others (namely, puppets suffering from colds and toothaches). Even preschoolers realized that contagion is domain specific (e.g. scraped knees are not contagious) and that immanent justice cannot explain why people get colds. Thus, even early understandings of the transmission of certain sorts of illness may honor domain-specific boundaries.

Summary

Children treat biology as a distinct domain in the sense of having an ontology of biological kinds (at least including animals) and having biologically specific causal beliefs that apply to members of that ontology. There is as yet, however, no research that attempts to describe something like a coherent naive biological theory and to determine whether young children's biological understanding is theory-like in this final sense. In the absence of such research, current studies suggest that naive biology may not be a highly developed domain. It may not be as coherently developed or organized as naive psychology, for example, in the preschool years. Nonetheless, preschoolers' biological reasoning cannot be reduced to domain-general principles (such as similarity) and seems clearly distinguished from psychology as a domain.

CONCLUSIONS

Infants and children rapidly acquire several framework theories of core domains—certain foundational understandings of the world that in turn frame further conceptual acquisitions. This proposal has generated exciting new research, some of it reviewed here. This perspective also raises several fundamental questions deserving further discussion. One particularly critical question is, how would one test and therefore potentially disconfirm the hypothesis that early understandings develop within distinct domains of thought?

This is a complicated question; a number of broad and complex claims are involved, and no proposal of this scope is confirmed or disconfirmed alone, but competes with alternative frameworks. The question of confirmation thus intimately includes the question of what this position tells us that is novel, and not discernible from Piagetian or information-processing views. Although the issues are complex, one can still test major assumptions and compare alternative hypotheses. Three assumptions to be tested emerge if we consider foundational knowledge as something like commonsense framework theories. These assumptions are the ones noted throughout the chapter: (*a*) Children honor core ontological distinctions; (*b*) children use specific causal principles in reasoning about particular domains; and (*c*) children's causal beliefs cohere and form a larger interconnected framework. These assumptions guide but also find support in the research we have reviewed; consequently the findings contrast with those expected from Piagetian or domain-general information-processing approaches.

As described in our introduction, Piaget's standard theory characterizes cognition in terms of increasingly content-free logical structures. The findings here argue instead for content-specific systems of knowing—forms of reasoning and knowledge acquisition tailored to specific objects of thought. The studies document impressive reasoning in young children, but limited to certain contents only. Concern with the specific contents of children's knowledge was apparent in Piaget's earlier research, albeit de-emphasized in his later theory. In his early writings Piaget (1929, 1930) described the content of young children's knowledge of the world as simultaneously animistic, realistic, artificialistic, and impervious to causal reasoning. Piaget's claims here are complex, but the essence is that until age 6 or 7 children fail to distinguish among three domains of thought that adults categorically separate—naive mechanics, psychology, and biology. The research we reviewed, however, documents young children's firm distinctions among these foundational systems of thought. Well before the start of formal schooling, children distinguish the physical world, the animate world, and the mental world and begin to reason appropriately about these three quite different realms of explanation.

An alternative explanation for these findings might be that apparently knowledgeable answers result from domain-general information-processing procedures. What look like ontological distinctions could reflect similarity-based categorizations summing over clusters of similar and dissimilar features. But research that we reviewed (especially in the section on naive biology) demonstrates that such domain-general similarity reasoning inadequately accounts for children's judgments. Similarly, what looks like causal reasoning specific to physical dynamics, for example, might reflect some domain-general Humean reasoning procedures for detecting continuities, contiguities, and covariations. But research that we reviewed (especially in the section on physical causality) documents that general causal reasoning schemes fail to account for young children's abilities to reason about specific causal mechanisms. Indeed across the three sections children exhibit three very different forms of causal reasoning, involving in the case of naive physics a kernel sense of mechanical forces; in the case of naive psychology a kernel sense of belief-desire causation; and in the case of naive biology a kernel sense of biological functions.

While we have focused on children's understanding of core distinctions, it would be incorrect to conclude that children honor all major distinctions that adults do. In fact the opposite seems true. Young children's early understanding of mental states, for example, includes desire, perception, and emotion but does not include belief. Their early understanding of biology includes animals but tends to exclude plants. Such findings do not argue against the notion that children have framework theories; they argue instead that children's frameworks differ substantially from those of adults. It would be troubling for a domain-specific foundational-knowledge position, however, if when probing for children's ontologies we found that they collapsed every important distinction. If children collapsed mental and physical, living and nonliving, animate and inanimate, perception and desire, there would be no firm ground on which to build content-specific frameworks and theories. The picture of the child as confusing these fundamental distinctions is close to Piaget's characterization; that is why research continues to test itself against Piaget's claims.

A description of young children as knowledgeable about several core domains has important implications for research methodology, implications that provide further tests of the general approach. Specifically, research of the sort reviewed here is often summarized as documenting early competence—unexpected understandings in young children and infants. A typical description of the methodological successes of such research is that investigators have succeeded in simplifying assessment tasks by making them easier, stripping away unnecessary processing demands, and removing complexity. This leads to a concomitant description of the nature of early development itself: Initial developments constitute first fragile, almost ephemeral understandings that are strengthened and consolidated as children become increasingly consistent in the face of more difficult task demands. Surely these descriptions are partly correct: Good experimental methods require removing unnecessary noise and achieving more accurate assessments; part of development entails increasing information processing fluency and consolidating initial partial understandings.

However, we believe it is misleading to characterize investigators' more sensitive tasks and methods as merely reducing task demands. Instead, if we assume that children are acquiring core understandings of certain domains, then experimenters succeed only when they tap into those core understandings. The investigator's ingenuity is needed not so much for simplification in a domain-neutral information-processing sense, as for simplification in the sense of accommodating more precisely to infants' and children's core understandings. Such core understandings can often be different from our own (e.g. an understanding of desires without a concomitant understanding of beliefs), and hence tasks require considerable calibration to the child's world. But our tasks need not be simple or easy in some theory-free sense. In our estimation, for example, Goswami & Brown's (1989) analogical reasoning tasks reveal competence in young children not because they are simple or stripped down but because they target children's core understandings of certain physical-causal events; Estes et al's (1989) tasks for probing children's understanding of mental entities are not less demanding than Piaget's clinical interviews; rather, they more precisely help children focus on the core distinctions in question; Rosengren et al's (in press) questions about growth and metamorphosis are not just simple, they tap children's understanding of natural biological transformations.

When, if ever, do children's early conceptualizations cohere into sensible theory-like systems of understanding? The charge of coherence is perhaps the most difficult one to assess empirically. Without it, however, we would not wish to ascribe foundational frameworks to children. Coherence is sometimes confused with consistency, but the two are distinct in an important way. Coherence refers to whether different beliefs make reference to or depend on one another; consistency refers to whether different beliefs contradict one another. One can have consistency without coherence, by holding noncontradictory beliefs that are unrelated. (We thank Doug Medin for calling our attention to this point.) For example, the beliefs "2 + 2 = 4" and "Earth is round" are consistent with one another but not coherent. Likewise, one can have coherence without full (global) consistency. That is, one can hold beliefs that make reference to other beliefs (i.e. that are not just isolated facts) but allow for some contradictions. In such cases, consistency might be only *local*.

In the present context, the distinction between coherence and consistency is particularly important when trying to assess whether children's belief systems are coherent. We need to examine whether children's beliefs cross-reference one another, and not whether contradictory beliefs are held. Wellman (1990) claims to show, for example, that children's reasoning about the mind coheres in a rich network of interwoven terms and inferences. Similarly, Keil (1989) has proposed that everyday theories entail a "causal homeostasis," in which causal links mutually reinforce other causal links. Still, in much of the research we reviewed, the question of coherence remains unaddressed.

However, several attacks on the problem seem possible. For example, patterns of inductive inference may be a useful guide to the degree of coherence in a domain. To the extent that a new piece of knowledge introduced in one part of the domain has ramifications for beliefs in a very different part of the domain, we have positive evidence for some coherence among concepts in the domain. If such evidence cannot be found, then children's beliefs may not have the status of framework theories. Similarly, if children are embracing framework theories of understanding then, paradoxically, they might do better on certain tasks that are made deliberately complex, enriched, and elaborated. We owe this suggestion to Karen Bartsch (see Bartsch 1991). A task that has much information to process, but information that rests on the coherent complexity central to the framework in question, may prove easier for a young child to understand and hence perform well on than a stripped down, bare-bones, and in that sense simplified version of the same task. Detailed presentations may aid rather than confuse young children by helping them recognize the elaborated domain of reasoning involved.

Similarly, if children first acquire *framework* understandings rather than specific knowledge of concrete phenomena, then we could expect children's understandings and beliefs to appeal to the framework involved even in the absence of specific knowledge. That is, their conceptualization may be sensible before being accurate. Sensitivity to larger forms of thinking in the absence of detailed information seems to us to be evident in much of the research we have reviewed. For example, 3- and 4-year-olds appear to know that various objects have insides and that such insides are important to identity and function, while at the same time being inaccurate or vague about just what those insides are (Gelman 1987; Gelman & Wellman 1991). Three-year-olds, like adults, tend to explain human action by appeal to the beliefs and desires of the actor; however, their sense of what the actor's beliefs and desires really are is often vague ("she just wanted to"), distorted, or wrong (Bartsch & Wellman 1988). Children appear to understand the animate-inanimate distinction, in essence, at an early age (Gelman et al 1983) but often do not know where various entities, such as plants, fall with regard to that distinction (Richards & Siegler 1986). In short, young children often seem to invoke a larger domain of understanding before evidencing accurate or detailed understandings of the specifics of that domain (see also Mandler et al 1991).

A similar sort of conclusion is found in R. Gelman's (1990) description of "skeletal principles" that define domains of cognitive development. For example, in her research on early understanding of numbers, she concludes that several counting principles define the child's early sense of numerosity and thereby shape a domain of number understanding for further exploration, development, and articulation. Gelman characterizes such formative domains "in terms of a set of interrelated principles that define entities and operations on them" (p. 81). This parallels the way we construe framework understandings that specify ontologies and modes of reasoning. Early cognitive development, we believe, requires description in terms of foundational frameworks; foundational frameworks that shape acquisition of a rich set of specific understandings rather than resulting from abstraction off of such specifics.

If such foundational theories of core domains are apparent by age 2, 3, or 4, a set of intriguing and as yet unanswered questions arise. One concerns the course of conceptual development. Infants, we now know, make many sophisticated perceptual discriminations and probably possess a representational system that allows conceptualization about the products of such perceptual analyses (Mandler 1988). Research and theory are only beginning to consider the nature of the infant conceptualizations that lead to the foundational theories of 3-year-olds and have only begun to glimpse how such early conceptual development proceeds. At what points and how is foundational knowledge dependent on perceptual analyses evident in young infants; how is early conceptual knowledge represented; how do different core domains of thinking change, restructure, and differentiate (cf. Mandler, 1988; Carey & Gelman 1991)?

Another set of questions concerns how foundational understandings influence and are influenced by cultural systems (including science itself). How are the belief systems of young children across a variety of cultures related? Currently, the evidence draws from a range of countries in North America, Western Europe, and Asia; however, these questions are only beginning to be explored in any detail in societies with more divergent, less industrial, less literate cultures and beliefs. The story here is bound to be complex; it is extremely unlikely that these conceptions are either simply innate or entirely learned, either simply universal or entirely culture-specific. Consider early acquisition of a theory of mind. Some initial social understandings are necessary for infants to enter into the complex and instructive social life of their family and culture. According to initial framework hypotheses, the infant embarks on a *collaborative* research program, the results of which are proximally the 3-year-old's theory of mind (or of biology or physics) and distally the adult's folk psychology (biology, physics) of his or her culture.

Although we have referred to these understandings as naive theories, they need not be influenced by scientific theories. Thus, our view of framework theories does not derive from claims in philosophy of language that scientific knowledge fixes or underwrites everyday knowledge or reference. If anything, we propose that the weightier influence is likely to be the other way around—naive frameworks may prime or motivate scientific theory-making, at least until scientific theories develop and break away from commonsense on their own. Thus, observations that children are poor scientific reasoners (Kuhn 1989), or that many cultures do not formulate scientific theories (Atran 1990), do not imply that children cannot have or develop framework theories. Children and lay adults are nonscientists (see Strauss 1988); nonetheless, their thinking appears to be framed by initial hypotheses or modes of construal that function for them as framework theories function for scientists. Such initial frameworks establish informal research programs that constrain and enable children to search for and acquire further information about the world. Indeed, historically the first framework theories in a science may well grow directly out of these naive framework theories, before the processes of explicit scientific formulation, test, and revision take hold.

Several questions remain with regard to domains, theories, and domain-specific cognitive development; we do not contend that a concern with foundational domains and framework theories resolves them all. However, we do contend that a central mechanism of cognitive development is the early acquisition of foundational theories of core domains of human understanding.

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Literature Cited

Adamson, L. B., Bakeman, R. 1985. Affect and attention: infants observed with mothers and peers. *Child Dev.* 56:582–93

Atran, S. 1990. *Cognitive Foundations of Natural History*. Cambridge: Cambridge Univ. Press

Baillargeon, R. 1992. The object concept revisited. In *Visual Perception and Cognition in Infancy. Carnegie-Mellon Symposia on Cognition*, Vol. 23. Hillsdale, NJ: Erlbaum. In press

Baillargeon, R., Spelke, E. S., Wasserman, S. 1985. Object permanence in five-month-olds. *Cognition* 20:191–208

Baltes, P. B., Baltes, M. M. 1990. *Successful Aging*. Cambridge: Cambridge Univ. Press

Baron-Cohen, S. 1990. Autism: a specific cognitive disorder of "mind-blindness." *Int. Rev. Psychiatry* 2:81–90

Baron-Cohen, S., Leslie, A. M., Frith, U. 1985. Does the autistic child have a "theory of mind?" *Cognition* 21:37–46

Bartsch, K. 1991. Children's reasoning about beliefs in the context of desires. Paper presented at the Bienn. Meet. Soc. Res. Child Dev., Seattle

Bartsch, K.,Wellman, H. M. 1989. Young children's attribution of action to beliefs and desires. *Child Dev.* 60:946–64

Bates, E., Bonigni, L., Bretherton, I., Camaioni, L., Volterra, V. 1979. *The Emergence of Symbols: Cognition and Communication in Infancy*. New York: Academic

Berlin, B., Breedlove, D., Raven, P. 1973. General principles of classification and nomenclature in folk biology. *Am. Anthropol.* 75:212–42

Bertenthal, B. I., Proffitt, H. D. R., Spetner, N. B., Thomas, M. A. 1985. The development of infant sensitivity to biomechanical motions. *Child Dev.* 56:531–43

Bibace, R., Walsh, M. E. 1981. Children's conceptions of illness. In *New Directions for Child Development: Children's Conceptions of Health, Illness, and Bodily Functions*, ed. R. Bibace, M. E. Walsh, No. 14, pp. 31–48. San Francisco: Jossey-Bass

Bowlby, J. 1969. *Attachment and Loss*. Vol. 1. *Attachment*. New York: Basic Books

Bretherton, I., McNew, S., Beeghly-Smith, M. 1981. Early person knowledge as expressed in gestural and verbal communication: When do infants acquire a "theory of mind?" In *Social Cognition in Infancy*, ed. M. Lamb, L. Sherrod, pp. 333–73. Hillsdale, NJ: Erlbaum

Brown, R. 1973. *A First Language*. Cambridge, MA: Harvard Univ. Press

Bruner, J. S. 1964. The course of growth. *Am. Psychol.* 19:1–15

Bullock, M., Gelman, R., Baillargeon, R. 1982. The development of causal reasoning. In *The Developmental Psychology of Time*, ed. W. J. Friedman, pp. 209–54. New York: Academic

Butterworth, G. E. 1991. The ontogeny and phylogeny of joint visual attention. In *Natural Theories of Mind*, ed. A. Whiten, pp. 223–32. Oxford: Basil Blackwell

Carey, S. 1985. *Conceptual Change in Childhood*. Cambridge, MA: MIT Press

Carey, S. 1991. Knowledge acquisition: enrichment or conceptual change? In *The Epigenesis of Mind: Essays on Biology and Cognition*, ed. S. Carey, R. Gelman, pp. 257–91. Hillsdale, NJ: Erlbaum

Carey, S., Gelman, R. 1991. *The Epigenesis of Mind: Essays on Biology and Cognition*. Hillsdale, NJ: Erlbaum

Case, R. 1985. *Intellectual Development: Birth to Adulthood*. New York: Academic

Chapman, M. 1988. *Constructive Evolution: Origins and Development of Piaget's Thought*. New York: Cambridge Univ. Press

Chase, W. G., Simon, H. A. 1973. Perception in chess. *Cogn. Psychol.* 4:55–81

Chi, M. T. H. 1978. Knowledge structure and memory development. In *Children's Thinking: What Develops?*, ed. R. Siegler, pp. 73–96. Hillsdale, NJ: Erlbaum

Chomsky, N. 1975. *Reflections on Language*. New York: Random House

Clough, E. E., Wood-Robinson, C. 1985. Children's understanding of inheritance. *J. Biol. Educ.* 19:304–10

D'Andrade, R. 1987. A folk model of the mind. In *Cultural Models in Language and Thought*, ed. D. Holland, N. Quinn, pp. 112–48. Cambridge: Cambridge Univ. Press

Deadman, J. A., Kelly, P. J. 1978. What do secondary school boys understand about evolution and heredity before they are taught the topics? *J. Biol. Educ.* 12:7–15

DeCasper, A. S., Fifer, W. P. 1980. Of human bonding: Newborns prefer their mothers' voices. *Science* 208:1174–76

Dolgin, K., Behrend, D. 1984. Children's knowledge about animates and inanimates. *Child Dev.* 55:1646–50

Estes, D., Wellman, H. M., Woolley, J. D. 1989. Children's understanding of mental phenomena. *Adv. Child Dev. Behav.* 22:41–87

Feinman, S. 1985. Emotional expression and preparedness for learning in infancy. In *Development of Expressive Behavior: Biology-Environment Interaction*, ed. G. Zivin, pp. 291–318. New York: Academic

Fischer, K. W., Silvern, L. 1985. Stages and individual differences in cognitive development. *Annu. Rev. Psychol.* 36:613–48

Flavell, J. H., Flavell, E. R., Green, F. L., Moses, L. J. 1990. Young children's understanding of fact beliefs versus value beliefs. *Child Dev.* 61:915–28

Flavell, J. H., Green, F. L., Flavell, E. R. 1986. *Development of Knowledge about the Appearance-Reality Distinction*. Monogr. Soc. Res. Child Dev. 51(212). Chicago: Univ. Chicago Press

Fodor, J. A. 1983. *Modularity of Mind*. Cambridge MA: MIT Press

Gallistel, C. R. 1990. *The Organization of Learning*. Cambridge, MA: MIT Press

Gelman, R. 1987. "Cognitive development: Principles guide learning and contribute to conceptual coherence." Invited address to Am. Psychol. Assoc. Meet., NY

Gelman, R., Baillargeon, R. 1983. A review of some Piagetian concepts. In *Handbook of Child Psychology*,, ed. J. H. Flavell, E. M. Markman, 3:167–230. New York: John Wiley

Gelman, R., Spelke, E. 1981. The development of thoughts about animate and inanimate objects: implications for research on social cognition. In *Social Cognitive Development*, ed. J. H. Flavell, L. Ross, pp. 43–66. Cambridge: Cambridge Univ. Press

Gelman, R., Spelke, E. S., Meck, E. 1983. What preschoolers know about animate and inanimate objects. In *The Acquisition of Symbolic Skills*, ed. D. Rogers, J. A. Sloboda, pp. 297–324. New York: Plenum

Gelman, S. A., Coley, J. D. 1991. Language and categorization: the acquisition of natural kind terms. In *Perspectives on Language and Thought: Interrelations in Development*, ed. S. A. Gelman, J. P. Bymes. Cambridge: Cambridge Univ. Press. In press

Gelman, S. A., Collman, P., Maccoby, E. E. 1986. Inferring properties from categories versus inferring categories from properties: the case of gender. *Child Dev.* 57:396–404

Gelman, S. A., Kremer, K. E. 1991. Understanding natural cause: children's explanations of how objects and their properties originate. *Child Dev.* 62:396–414

Gelman, S. A., O'Reilly, A. W. 1988. Children's inductive inferences within superordinate categories. *Child Dev.* 59:876–87

Gelman, S. A., Wellman, H. M. 1991. Insides and essences: early understandings of the non-obvious. *Cognition* 38:213–44

Golinkoff, R. M. 1983. Infant social cognition: self, people, and objects. In *Piaget and the Foundations of Knowledge*, ed. L. Liben, pp. 179–200. Hillsdale, NJ: Erlbaum

Golinkoff, R. M., Harding, C. G., Carlson, V., Sexton, M. E. 1984. The infant's perception of causal events: the distinction between animate and inanimate objects. In *Advances in Infancy Research*, ed. L. L. Lipsitt, C. Rovee-Collier, Vol. 3. pp. 146–65. Norwood, NJ: Ablex

Golinkoff, R. M., Markessini, J. 1980. "Mommy sock": the child's understanding of possession as expressed in two-noun phrases. *J. Child Lang.* 7:119–36
Gopnik, A., Astington, J. W. 1988. Children's understanding of representational change and its relation to the understanding of false belief and the appearance-reality distinction. *Child Dev.* 59:26–37
Goswami, U. 1991. Analogical reasoning: What develops? A review of research and theory. *Child Dev.* 62:1–22
Goswami, U., Brown, A. L. 1989. Melting chocolate and melting snowmen: analogical reasoning and causal relations. *Cognition* 35:69–95
Hadwin, J., Perner, J. 1991. Pleased and surprised: children's cognitive theory of emotion. *Br. J. Dev. Psychol.* 9:215–34
Hala, S., Chandler, M., Fritz, A. S. 1991. Fledgling theories of mind: deception as a marker of 3-year-olds' understanding of false belief. *Child Dev.* 62:83–97
Harris, P. L. 1983. Infant Cognition. In *Handbook of Child Psychology*. Vol. 2. *Infancy and Developmental Psychobiology*, ed. M. Haith, J. Campos, pp. 699–782. New York: Wiley
Harris, P. L. 1989. *Children and Emotion.* Oxford: Basil Blackwell
Harris, P. L., Brown, E., Marriot, C., Whithall, S., Harmer, S. 1991. Monsters, ghosts and witches: testing the limits of the fantasy-reality distinction in young children. *Br. J. Dev. Psychol.* 9:105–23
Hornick, R., Risenhoover, N., Gunnar, M. 1987. The effects of maternal positive, neutral, and negative affective communications and infant responses to new toys. *Child Dev.* 58:937–44
Inagaki, K. 1990. Young children's everyday biology as the basis for learning school biology. *Bull. Faculty Educ., Chiba Univ.* 38:177–84
Inagaki, K., Hatano, G. 1988. Young children's understanding of the mind-body distinction. Paper presented at the Meet. Am. Educ. Res. Assoc., New Orleans
Jones, S. S., Smith, L. B., Landau, B. 1992. Object properties and knowledge in early lexical learning. *Child Dev.* In press
Kail, R., Hagen, J. 1977. *Perspectives on the Development of Memory and Cognition.* Hillsdale, NJ: Erlbaum
Kaiser, M. K., Proffitt, D. R., Anderson, K. 1985. Judgments of natural and anomalous trajectories in the presence and absence of motion. *J. Exp. Psychol.: Learn., Mem., Cogn.* 11:795–803
Kaiser, M. K., Proffitt, P. G. 1986. Swingtime: observers' sensitivity to the dynamics of pendulums. Paper presented at the Annu. Meet. Psychonom. Soc., New Orleans
Kaiser, M. K., McCloskey, M., Proffitt, D. R. 1986. Development of intuitive theories of motion. *Dev. Psychol.* 22:67- 71
Kargbo, D., Hobbs, E., Erickson, G. 1980. Children's beliefs about inherited characteristics. *J. Biol. Educ.* 14:137–46
Karmiloff-Smith, A., Inhelder, B. 1975. If you want to get ahead, get a theory. *Cognition* 3:195–212
Keil, F. C. 1979. *Semantic and Conceptual Development.* Cambridge, MA: Harvard Univ. Press
Keil, F. C. 1986. The acquisition of natural kind and artifact terms. In *Language Learning and Concept Acquisition,* ed. W. Demopoulos, A. Marras, pp. 133–53. Norwood, NJ: Ablex
Keil, F. C. 1989. *Concepts, Kinds, and Cognitive Development.* Cambridge, MA: MIT Press
Kister, M. C., Patterson, C. J. 1980. Children's conceptions of the causes of illness: understanding of contagion and use of immanent justice. *Child Dev.* 51:839–49
Kohlberg, L. 1966. A cognitive-developmental analysis of children's sex-role concepts and attitudes. In *The Development of Sex Differences* ed. E. E. Maccoby, pp. 82–173. Stanford, CA: Stanford Univ. Press
Kuhn, D. 1989. Children and adults as intuitive scientists. *Psychol. Rev.* 96:674–89
Kuhn, T. 1962. *The Structure of Scientific Revolutions.* Chicago: Univ. Chicago Press
Lakatos, I. 1970. Falsification and the methodology of scientific research programmes. In *Criticism and the Growth of Knowledge,* ed. I. Lakatos, I. Musgrave, pp. 91–196. Cambridge: Cambridge Univ. Press
Laudan, L. 1977. *Progress and Its Problems: Towards a Theory of Scientific Growth.* Berkeley: Univ. Calif. Press
Laurendeau, M., Pinard, A. 1962. *Causal Thinking in the Child: A Genetic and Experimental Approach.* New York: International Universities Press
Lempers, J. D., Flavell, E. R., Flavell, J. H. 1977. The development in very young children of tacit knowledge concerning visual perception. *Gen. Psychol. Monogr.* 95:3–53
Leslie, A. M. 1982. The perception of causality in infants. *Perception* 11:173–86
Leslie, A. M. 1988. The necessity of illusion: perception and thought in infancy. In *Thought without Language,* ed. L. Weiskrantz, pp. 185–210. Oxford: Clarendon Press
Leslie, A. M., Keeble, S. 1987. Do six-month-old infants perceive causality? *Cognition* 25:265–88
Lewis, C., Osbourne, A. 1990. Three-year-olds' problems with false belief: conceptual deficit or linguistic artifact? *Child Dev.* 61:1514–19
Liben, L. S., Signorella, M. L., eds. 1987. *New Directions for Child Development:*

Children's Gender Schemata, No. 38. San Francisco: Jossey-Bass

Mandler, J. 1988. How to build a baby: on the development of an accessible representational system. *Cogn. Dev.* 3:113–36

Mandler, J. M., Bauer, P. J., McDonough, L. 1991. Separating the sheep from the goats: differentiating global categories. *Cognit. Psychol.* 23:263–98

Massey, C. M., Gelman, R. 1988. Preschooler's ability to decide whether a photographed unfamiliar object can move itself. *Dev. Psychol.* 24:307–17

Masur, E. F. 1983. Gestural development, dual-directional signaling, and the transition to words. *J. Psycholinguist. Res.* 12:93–109

Mayr, E. 1988. *Toward a New Philosophy of Biology: Observations of an Evolutionist.* Cambridge, MA: Harvard Univ. Press

McCloskey, M. 1983. Naive theories of motion. In *Mental Models,* ed. D. Gentner, A. Stevens, pp. 299–324. Hillsdale, NJ: Erlbaum

Medin, D. 1989. Concepts and conceptual structure. *Am. Psychol.* 44:1469–81

Meltzoff, A. N., Moore, M. K. 1983. Newborn infants imitate adult facial gestures. *Child Dev.* 54:702–19

Morton, A. 1980. *Frames of Mind.* Oxford: Clarendon Press

Moses, L. J. 1990. *Young children's understanding of intention and belief.* PhD thesis, Stanford Univ.

Murphy, G. L., Medin, D. L. 1985. The role of theories in conceptual coherence. *Psychol. Rev.* 92:284–316

Nelson, L. A. 1987. The recognition of facial expressions in the first two years of life: mechanisms of development. *Child Dev.* 58:889–909

Oakes, L. M., Cohen, L. B. 1990. Infant perception of a causal event. *Cogn. Dev.* 5:193–207

Perner, J., Leekam, S. R., Wimmer, H. 1987. Three-year-olds' difficulty with false belief. *Br. J. Dev. Psychol.* 5:125–37

Piaget, J. 1929. *The Child's Conception of the World.* London: Routledge & Kegan Paul

Piaget, J. 1930. *The Child's Conception of Physical Causality.* London: Routledge & Kegan Paul

Piaget, J. 1932. *The Moral Judgment of the Child.* London: Routledge & Kegan Paul

Piaget, J. 1954. *The Construction of Reality in the Child.* Basic Books

Pillow, B. H. 1989. Early understanding of perception as a source of knowledge. *J. Exp. Child Psychol.* 47:116–29

Poulin-Dubois, D., Shultz, T. R. 1988. The development of the understanding of human behavior: from agency to intentionality. In *Developing Theories of Mind,* ed. J. Astington, P. Harris, D. Olson, pp. 109–25. New York: Cambridge Univ. Press

Pratt, C., Bryant, P. E. 1990. Young children understand that looking leads to knowing (so long as they are looking into a single barrel). *Child Dev.* 61:973–82

Premack, D. 1990. The infant's theory of self-propelled objects. *Cognition* 36:1–16

Proffitt, D. R., Kaiser, M. K., Whelan, S. M. 1990. Understanding wheel dynamics. *Cogn. Psychol.* 22:342–73

Rholes, W. S., Newman, L. S., Ruble, D. N. 1990. Understanding self and other: developmental and motivational aspects of perceiving persons in terms of invariant dispositions. In *Handbook of Motivation and Cognition: Foundations of Social Behavior,* ed. E. Higgins, R. Sorrentino, 2:369–407. New York: Guilford

Richards, D. D., Siegler, R. S. 1984. The effects of task requirements on children's abilities to make life judgments. *Child Dev.* 55:1687–96

Richards, D. D., Siegler, R. S. 1986. Children's understandings of the attributes of life. *J. Exp. Child Psychol.* 42:1–22

Rosengren, K. S., Gelman, S. A., Kalish, C. W., McCormick, M. 1992. As time goes by: children's early understanding of growth in animals. *Child Dev.* In press

Schwartz, S. P. 1977. Introduction. In *Naming, Necessity, and Natural Kinds,* ed. S. P. Schwartz, pp. 13–41. Ithaca, NY: Cornell Univ. Press

Shatz, M., Wellman, H. M., Silber, S. 1983. The acquisition of mental verbs: a systematic investigation of first references to mental state. *Cognition* 14:301–21

Sherrod, L. R. 1981. Issues in cognitive-perceptual development: the special case of social stimuli. In *Infant Social Cognition: Empirical and Theoretical Considerations,* ed. M. Lamb, L. Sherrod, pp. 11–36. Hillsdale, NJ: Erlbaum

Shultz, T. R. 1982. *Rules of Causal Attribution.* Monogr. Soc. Res. Child Dev. 194. Chicago: Univ. Chicago Press

Shultz, T. R., Kestenbaum, N. R. 1985. Causal reasoning in children. In *Annals of Child Development,* ed. G. Whitehurst, Vol. 2. pp. 195–244. Greenwich, CT: JAI Press

Shultz, T. R., Pardo, S., Altman, E. 1982. Young children's use of transitive inference in causal chains. *Br. J. Psychol.* 73:235–41

Shultz, T. R., Wells, D., Sarda, M. 1980. Development of the ability to distinguish intended actions from mistakes, reflexes, and passive movements. *Br. J. Soc. Clin. Psychol.* 19:301–10

Siegal, M. 1988. Children's knowledge of contagion and contamination as causes of illness. *Child Dev.* 59:1353–59

Siegal, M., Beattie, K. 1992. Where to look first for children's understanding of false beliefs. *Cognition.* In press

Siegal, M., Robinson, J. 1987. Order effects

in children's gender constancy response. *Dev. Psychol.* 23:283–86
Siegler, R. S. 1989. Mechanisms of cognitive development. *Annu. Rev. Psychol.* 40:353–79
Smith, C., Carey, S., Wiser, M. 1985. On differentiation: a case study of the development of the concepts of size, weight, and density. *Cognition* 21:177–237
Smith, J., Russell, G. 1984. Why do males and females differ? Children's beliefs about sex differences. *Sex Roles* 11:1111–20
Smith, L. B. 1989. In defense of perceptual similarity. Paper presented at the Meet. Soc. Res. Child Dev., Kansas City
Smith, L. B., Heise, D. 1992. Perceptual similarity and conceptual structure. In *Percepts, Concepts, and Categories: The Representation and Processing of Information,* ed. B. Burns. New York: Elsevier. In press
Spelke, E. S. 1988. Where perceiving ends and thinking begins: the apprehension of objects in infancy. *Minn. Symp. Child Psychol.* 20:197–234
Spelke, E. S. 1991. Physical knowledge in infancy. In *The Epigenesis of Mind: Essays on Biology and Cognition,* ed. S. Carey, R. Gelman, pp. 133–69. Hillsdale, NJ: Erlbaum
Springer, K., Keil, F. C. 1989. On the development of biologically specific beliefs: the case of inheritance. *Child Dev.* 60:637–48
Stavy, R., Wax, N. 1989. Children's conceptions of plants as living things. *Hum. Dev.* 32:88–94
Stein, N. L., Levine, L. J. 1987. Thinking about feelings: the development and organization of emotional knowledge. In *Aptitude, Learning, and Instruction.* Vol. 3. *Cognition, Conation, and Affect,* ed. R. Snow, M. Farr, pp. 165–98. Hillsdale, NJ: Erlbaum
Stein, N. L., Levine, L. J. 1989. The causal organization of emotional knowledge: a developmental study. *Cogn. Emot.* 3:343–78
Stern, D. N. 1985. *The Interpersonal World of the Infant.* New York: Basic Books
Stevenson, H. W., Lee, S. Y., Stigler, J. W. 1986. Mathematics achievement of Chinese, Japanese, and American children. *Science* 231:693–99
Stigler, J. W., Shweder, R. A., Herdt, G. 1990. *Cultural Psychology: Essays on Comparative Human Development.* Cambridge: Cambridge Univ. Press
Stitch, S. P. 1983. *From Folk Psychology to Cognitive Science: The Case Against Belief.* Cambridge, MA: MIT Press
Strauss, S. 1988. *Ontogeny, Phylogeny, and Historical Development.* Norwood, NJ: Ablex
Taylor, M. G., Gelman, S. A. 1991. Children's beliefs about sex differences: the role of nature vs. nurture. Paper presented at the Meet. Soc. Res. Child Dev., Seattle
Taylor, M. 1988. Conceptual perspective taking: children's ability to distinguish what they know from what they see. *Child Dev.* 59:703–18
Teale, W., Sulzby, E. 1986. *Emergent Literacy: Reading and Writing.* Norwood, NJ: Ablex
Thomas, K. 1983. *Man and the Natural World.* New York: Pantheon Books
Walden, T. A., Ogan, T. A. 1988. The development of social referencing. *Child Dev.* 59:1230–40
Wellman, H. M. 1990. *The Child's Theory of Mind.* Cambridge, MA: M. I. T. Press
Wellman, H. M. 1992. Early understanding of mind: the normal case. In *Understanding Other Minds: Perspectives from Autism,* ed. S. Baron-Cohen, H. Tager-Flusberg, D. Cohen, In press
Wellman, H. M., Bannerjee, M. 1991. Mind and emotion: children's understanding of the emotional consequences of beliefs and desires. *Br. J. Dev. Psychol.* 9:191–214
Wellman, H. M., Bartsch, K. 1988. Young children's reasoning about beliefs. *Cognition* 30:239–77
Wellman, H. M., Cross, D., Bartsch, K. 1986. Infant search and object permanance: a meta-analysis of the A-not-B error. *Monogr. Soc. Res. Child Dev.* 51(3)
Wellman, H. M., Estes, D. 1986. Early understanding of mental entities: a reexamination of childhood realism. *Child Dev.* 57:910–23
Wellman, H. M., Woolley, J. D. 1990. From simple desires to ordinary beliefs: the early development of everyday psychology. *Cognition* 57:245–75
Wimmer, H., Hogrefe, J., Sodian, B. 1988. A second stage in children's conceptions of mental life: understanding sources of information. In *Developing Theories of Mind,* ed. J. Astington, P. Harris, D. Oleson, pp. 173–92. New York: Cambridge Univ. Press
Wimmer, H., Perner, J. 1983. Beliefs about beliefs: representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition* 13:103–28
Yuill, N. 1984. Young children's coordination of motive and outcome in judgments of satisfaction and morality. *Br. J. Dev. Psychol.* 2:73–81
Zinober, B., Martlew, M. C. 1985. Developmental changes in four types of gesture in relation to acts and vocalizations from 10 to 21 months. *Br. J. Dev. Psychol.* 3:293–306