CHAPTER 11

Knowledge Acquisition in Foundational Domains

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In this chapter, we examine the emergence and development of children's foundational knowledge. By foundational knowledge we mean those concepts or bodies of knowledge that engender, shape, and constrain other conceptual understandings. To illustrate, according to Piaget (1954), late in infancy children begin to understand that physical objects co-exist with the self and that objects continue to exist whether or not the child perceives them. He claims that this fundamental insight frames the child's subsequent understanding of mechanical causation, human instrumental actions, space, time, and natural physical phenomena such as astronomy and geography. Arguably any piece of knowledge, no matter how obscure, could affect at least some other conceptions. However, certain understandings are also much more influential than others (e.g., the object concept vs. knowledge that cars are more often black than pink). The point here is not to draw a sharp dividing-line between foundational and nonfoundational knowledge, but rather to direct attention to knowledge that has a potentially powerful impact, during and throughout childhood.

Thought has structure, function, and content (Piaget, 1953). Knowledge is the content on which the mind works. Without knowledge, there would be no thought. Thus, it is not surprising that scholars have been interested in children's knowledge for decades. The array of content areas that have been explored is vast; including the shape of the earth, distinctions between dreams and waking reality, whether plants are alive, illness, numerosity, print, magnetism, and more. Until recently, however, the focus has rarely been on children's knowledge itself. Rather, theorists proposed that examining knowledge would provide a window onto more fundamental, domain-general structures and processes that children were using, such as categorization, memory, or logic. Piaget's research epitomizes this approach. He provided some of the most intriguing accounts of early knowledge, yet disavowed any interest in the "surface" level—that is, the knowledge itself.

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Currently, however, there is a renewed interest in knowledge, how it is organized, and how it changes over time. One reason for this interest is the recognition that specialized knowledge can exert powerful effects on cognition. In a variety of domains, experts—both children and adults—make use of concepts, principles, and procedures not available to novices (Chase & Simon, 1973; Chi, 1978).

Renewed interest in knowledge also derives from studies of naive, folk, or common sense theories. Common sense theories are people's ordinary understandings of certain bounded bodies of information, such as the set of ideas that nonscientists hold about celestial phenomena (folk astronomy). Various claims have been advanced by anthropologists, cognitive developmentalists, educators, and other cognitive scientists: that human concepts, for adults and children, are entrenched in naive theories (e.g., Murphy & Medin, 1985); that cultural worldviews are instantiated in folk theories that shape ways of thinking within particular societies (e.g., Holland & Quinn, 1987); that young children rapidly acquire certain basic theories that shape further cognitive acquisitions (e.g., Carey, 1985); and that naive theories deeply constrain learning via instruction (e.g., Vosniadou & Brewer, 1987).

A third source of increased interest in knowledge is the contemporary concern with domain-specific "modules" of thought. The general claim here is that the mind is heterogeneous—not general—different cognitive systems are designed to process and represent some sorts of information, not others (e.g., words vs. numbers). Several writers have strongly argued that domain-specific cognition has an evolutionary-neurological basis (e.g., Pinker, 1994; Sperber, 1994). Animals evolve special physical and sensory adaptations designed to solve certain problems or to take advantage of certain environmental affordances (e.g., eyes and ears, sight vs. echolocation, wings vs. fins). The same pressures could yield special conceptual adaptations as well—systems that process only specific sorts of information to arrive at specific sorts of representations. In humans, language is arguably a prime example (but see Bates, Bretherton, & Snyder, 1988; Tomasello, 1995). Developmentally, the representations generated by specific modules may provide a basic infrastructure for knowledge and its acquisition.

From several directions, therefore, foundational knowledge has become central to our efforts to understand cognitive development. The relevant research does not form a unitary literature; it abounds with competing assumptions, explanations, kinds of evidence, and conclusions. Nonetheless, a set of common questions guides these efforts: Are there core domains of human cognition? If so, how are these best characterized—as pockets of expertise, naive theories, or mental modules? When do these first appear in development—as early infrastructure or the later culmination of conceptual achievement? What accounts for their emergence? How much and in what ways do they change? Current research that tackles these questions sheds light on some of the most basic issues in the field.

Any approach to addressing these issues necessarily embodies certain assumptions. We outline some of the features and limits of our approach in the following three sections.

Target Domains

A claim of those interested in foundational knowledge is that certain systems of knowledge are especially important to human understanding. We focus on three that are arguably central to survival and everyday interactions: the domains of physics, psychology, and biology. Knowledge about other humans enables negotiating social interactions and managing important tasks of mating and childrearing; knowledge about plants and animals fosters food-gathering, avoiding predators, and maintaining health; knowledge about physical objects allows prediction of the effects of one's own and others' physical actions, the creation and use of tools, and so on. Moreover, these domains represent three areas in which considerable exciting research is being conducted. Other content areas, too, clearly have broad significance for children's reasoning but will not be covered here. These include language, number, space, time, morality, and social kinds (including gender and race). Most are covered elsewhere in this *Handbook*.

The three domains we review have roots in Piaget's work (Piaget, 1929, 1930). He argued that psychological, physical, and biological reasoning were fundamental systems of adult thinking and knowing. Thus, he conducted investigations of children's understanding of physical, psychological, and biological phenomena, prefiguring current work in these areas. Importantly, Piaget concluded that children's thinking does *not* honor fundamental adult distinctions among these domains; basic knowledge of these phenomena was said to develop relatively late in childhood. Young children, Piaget claimed, are animists, construing various physical phenomena (clouds moving, rivers flowing) as alive; they are realists, construing mental phenomena as concrete and physical (e.g., ideas are visible and tangible objects); and they are artificialists, construing natural phenomena as the products of human invention and intention (e.g., clouds come from the chimneys of houses). Piaget's arguments underscore a key question: Do children distinguish these three possible domains, and if so, when? Our review is shaped by two orienting perspectives for addressing this question. One concerns the nature of the evidence researchers might use to address the question. The other concerns possible explanatory accounts theorists have proposed for domain differences.

Evidence: Ontologies, Causes, and Unobservables

In order to infer that children's thought reflects distinct domains of understanding, it is not sufficient to demonstrate that children know about different sorts of things—that they have some information about people, some about physical objects, and some about plants and animals. Instead, we need evidence that children view these as distinctively different phenomena that require different sorts of reasoning. Although one could adopt a neurological approach (do different brain systems serve these different understandings?), instead we adopt a cognitive approach, and draw from philosophy of science for more conceptual criteria. Scientific bodies of knowledge certainly carve the world into distinctive domains. Consider the differences between physics and psychology. What features distinguish such profoundly different domains? Philosophers of science wrestle with this issue when they discuss paradigms or research traditions as opposed to specific scientific theories. Specific theories are detailed formulations about a delimited set of phenomena. Beyond specific theories, scientific endeavors also reflect more global paradigms (Kuhn, 1962), research programs (Lakatos, 1970), research traditions (Laudan, 1977), or what we have called framework theories (Wellman, 1990; Wellman & Gelman, 1992). Most important for the current discussion, framework theories carve out basic domains for scientific reasoning. They do so by outlining the ontology, basic causal devices, and underlying constructs pertinent to a domain.

> 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, p. 79)

Whether or not there are *everyday* framework theories (Brewer & Samarapungavan, 1991; Wellman, 1990), a consideration of these scientific frameworks highlights several features that we take to be critical to a consideration of core domains of thought: ontological distinctions, domain-specific causal modes of reasoning, underlying "theoretical" or nonobvious constructs, and coherent, interrelated systems of concepts. We aim to address when and in what ways children: (a) divide the world into fundamentally different kinds of "things"—for example, thoughts versus solid physical objects, (b) appreciate fundamentally different sorts of causes—for example, processes activated by collisions with solid objects versus processes activated by desires and intentions, (c) appeal to distinctive underlying constructs in their understandings—for example, the states that underpin human behavior versus the atoms and substances out of which solid objects are composed, and (d) create larger systems within which these concepts, causes, and constructs cohere.

In contrast to this sort of domain-specific reasoning, children's thinking could be based exclusively on more domain-general principles (Keil, 1989). For example, children might classify all sorts of objects—physical devices, persons, plants, and animals—using general principles of similarity (classifying entities by overall color, shape, movement). Children might reason causally about all phenomena in similar ways—identifying as causally important those events that reliably precede and covary with various outcomes, whatever their nature may be. We also want to consider, therefore, whether children at first understand phenomena in terms of domain-general, manifest features rather than domain-specific underlying constructs.

In sum, in what follows we consider whether and when children's thinking is shaped into three core domains of knowledge—naive physics, psychology, and biology—by considering whether children honor ontological distinctions among these domains, whether children use distinctive causal principles in reasoning about these domains, and whether children's beliefs within a domain appeal to unobservable, underlying constructs and cohere into interconnected networks of reasoning. These are empirical questions. Without examining children's language and behavior, one cannot know if children's thinking ever assembles itself in this fashion, or if so, at what point developmentally. Moreover, although framework scientific theories arguably demonstrate these qualities, children's thinking could be characterized by one, several, or none of these features. Similarly, we need not require that all these different qualities be evident in order to conclude that there are core domains of everyday cognition. Core domains could be defined in ways that privilege one or two rather than all these features. Consideration of ontological categories, coherence, causal beliefs, and understandings of the nonobvious, however, provides relevant distinctions to evaluate these and other claims.

Explanatory Accounts: Modules, Expertise, and Theories

Suppose children's thinking, early or late, demonstrates distinctive physical, biological, and psychological modes of reasoning. How might we account for these developments? Our second orienting perspective is to consider three classes of theoretical accounts that correspond, roughly, to three different metaphors of children's thought: child-as-adult, child-as-novice, and child-as-alien. These accounts differ with regard to several questions: How similar are the knowledge systems of children and adults? How can one characterize these knowledge systems? How similar are the mechanisms by which children and adults revise their knowledge (the process of conceptual change)? We focus primarily on the first two questions, though the third is also quite important (e.g., Kuhn, 1995).

On the child-as-adult metaphor, children are cognitively just like adults in having the same core conceptions and organizing knowledge in essentially the same ways. On this account, apparent differences between children's and adults' thought are essentially superficial. This view fits well with a common intuition that wholly new fundamental understandings may be impossible. If you don't already view the world as consisting of individual objects (as opposed to ever changing flashes of light and form), how could you ever discover this and how could you communicate with others who do? Even the simple conversational exchanges of parents and 2-year-olds would be impossible to achieve without a common set of concepts (e.g., "want" or "cookie") on which to draw. True, children often appear to lack fundamental adult knowledge or even to misconstrue simple phenomena. On this view, children's behavioral limitations—their limited memory, language, processing speed—obstruct our view of their knowledge. This competence-performance distinction intuitively fits with our common experience of knowing something but not being able to access or articulate it.

In contrast, the child-as-novice metaphor assumes that children start out knowing little or nothing of the world around them. Beginning with ignorance, children develop by gaining experience and so incrementally adding to their knowledge base. The power of expertise is seen with something so ordinary as the act of reading. We start out, as children, painstakingly deciphering words letter-by-letter, not even understanding what we read, but after many hours, then months, then years, of experience, we can perform the task so rapidly, so automatically, that the thoughts evoked by the writer seem to leap into our minds without effort.

Finally, the child-as-alien metaphor assumes that children's view of the world is potentially quite different from that of adults. (Note that the presumption of this metaphor is that children's knowledge is alien from adults; not that their brains are alien.) Basic conceptions that we cannot imagine someone without (such as expecting objects to continue to exist when out of sight) may not be shared by children. The point is that, rather than ignorance, children are thought to have their *own* ways of understanding the world. Intuitive insight into this view can be garnered from considering the qualitative changes that have occurred in the history of science (e.g., from a Newtonian to an Einsteinian physics). Moreover, something like cognitive revolutions occur within the minds of individuals (e.g., grasping algebra in high school, learning a new language, religious conversion).

These three metaphors correspond roughly to three distinctive theoretical approaches to knowledge acquisition, domain-specificity, and foundational knowledge. The counterparts to child-as-adult views are innatist, modular theories, the counterparts to child-as-novice views are expertise theories, and the counterparts to child-as-alien views are theory theories. Table 11.1 presents a summary of some of the distinctive characteristics of these three approaches.

Modular Theories

Chomsky argued that the mind is modular—"consisting of separate systems with their own properties" (Chomsky, 1988, p. 161). Claims of other theorists regarding modularity have varied in at least two respects: whether modularity is restricted to perceptual processes or affects central cognitive processes as well, and whether modularity is innate

TABLE 11.1 A Schematic Comparison among Modular, Theory Theory, and Expertise Approaches

	Dominant Metaphor	Mechanism	Role of Input	What Is Innate	Variability in Outcome	Sample Domains
Modules	child as adult	biological constraints	input as "trigger"	mandatory input-output systems	highly fixed and constrained	language, vision, theory of mind
Theories	child as alien	causal-explanatory understandings	input as source of data	skeletal principles and ontologies	variable within broad constraints	psychology, physics, biology
Expertise	child as novice	information-processing skills	input/experience foundational	information-processing strategies	highly variable	reading, dinosaurs, physics

or constructed. Modularity need not imply evolved innate modules (Karmiloff-Smith, 1992) but for most modular proponents it does, and that is the sort of modularity we address here. Nonetheless, all modularity views assume domain-specificity. Chomsky's focus was on language, and more specifically syntax or universal grammar. Evidence for the status of syntax as a module was its innate, biologically driven character—evident in all and only humans; its neurological localization and breakdown—the selective impairment of syntactic competence in some forms of brain damage; its rapid acquisition in the face of meager environmental data—syntactic categories of great abstraction, such as verb or subject, are easily acquired by small children faced with impoverished input; and the presence of critical periods and maturational timetables (Pinker, 1994). Fodor (1983) extended the logic of modules to cognitive abilities more broadly. He distinguished between central logical processes and perceptual systems, arguing for modularity of the latter. In Fodor's analysis, modules are innately specified systems that take in sensory inputs and yield necessary representations of them. The visual system as characterized by Marr (1982) provides a prototypic example—a system that takes visual inputs and generates 2½ dimensional representations of objects and space. Like the visual system, by Fodor's analysis, modules are not only innately specified, their processing is mandatory and encapsulated, and (unlike central knowledge and beliefs) their representational outputs are insensitive to revision via experience. Experience provides specific inputs to modules which yield mandatory representations of inputs. Certain experiential inputs may be necessary to trigger the module's working in the first place, but the processes by which the module arrives at its representations are mandatory rather than revisable.

Extending Fodor, several writers have argued that certain conceptual processes, not just perceptual ones, are modular (Karmiloff-Smith, 1992; Sperber, 1994) or supported by systems of cognitive modules (e.g. Atran, 1995; Baron-Cohen, 1995; Leslie, 1994). In these claims each module works independently, achieving its own special representations. Thus, for the most part, cognitive modules are like Fodor's perceptual ones, except that "perceptual processes have, as input, information provided by sensory receptors, and as output, a conceptual representation categorizing the object perceived . . . [whereas] conceptual processes have conceptual representations both as input and as output" (Sperber, 1994, p. 40).

It is important to distinguish the general claim that there is innate knowledge from the stronger claim that there are innate modules (e.g., Gopnik, 1993). It is conceivable that certain representations may be innately specified, yet fail to be modular, either because the knowledge is domain-general or because it is readily revisable on the basis of new experience. All sorts of knowledge, including expertise or naive theories, may include or begin from a base of innately specified representations. A crucial difference between nativist modular accounts and the others, therefore, concerns the nature of the interplay between experience and conceptual structure. Modular processes are mandatory in the sense that, assuming they come on line (and are not impaired), they result in conceptions that are necessary conversions of the relevant inputs into special representations, specified by that module.

Developmentally, this distinction between innate knowledge and innate modules concerns how open in principle development is considered to be: Are there a limited number of predetermined developmental endpoints or an essentially open-ended array of endpoints depending only on the information given and amount of time development takes? Modular accounts specify a limited number of endpoints in each domain; theories and expertise accounts encompass considerably more variable developmental possibilities.

Some modular accounts allow several alternative developmental endpoints arrived at by several branching routes. In these parameter-setting accounts, the modular representation can take one form or another depending on which value of a key parameter is available in that organism's developmental environment (e.g., Hyams, 1986). However, the relation between input and system here is still one of triggering; hence, the developmental options are fixed, and once set, the parameter cannot be readjusted. Modularity accounts may invoke external information processing limitations or performance constraints to explain certain sorts of developments. Still, on this view, early conceptual structures are like later ones; only various performance limitations prevent children from demonstrating their knowledge.

Expertise

The claim that expertise carves out domains begins with the following observation. With enough practice at a task, whether that task is the game of chess or the gathering of factual knowledge about dinosaurs, an ordinary person begins to look extraordinary. With sufficient experience, a person attains amazing feats of memory (Chase & Ericsson, 1981), reorganizes knowledge into complex hierarchical systems, and develops rich networks of causally related information (Chi, Hutchinson, & Robin, 1989). These abilities are so striking that they can even erase the usual developmental finding that adults outperform children (e.g., Chi, 1978).

Just as important, these abilities cannot be explained as individual differences in the general processing talents of experts. The same individual who is remarkable on the chessboard shows mundane performance on tasks outside the skill domain. For example, the chess expert's memory for a string of digits is quite ordinary. It seems, then, that these abilities are domain-specific, at least in some sense of domain. Furthermore they are foundational in that expertise influences further learning, attention to, and understanding of new domain-related information.

The notion of skill domains molded by expertise is distinct from modularity. With the former, there is no appeal to innate modules, innate constraints, or evolutionary forces. Consideration of expertise-driven skill domains poses an interesting challenge to other notions of domain specificity and foundational knowledge. First, the effects of expertise demonstrate the far-reaching influences of intensive experience. They remind us to take seriously the capacity of human cognition to shape itself to the world it finds as opposed to a world it may evolutionarily expect. Early humans could not have evolved special cognitive capacities to read; there was no world of print until humans invented it millennia later. Yet even relatively young children become expert readers evidencing a complex network of knowledge and processes of domain-like scope. A second point is that studies of expertise challenge us to consider what can count as a domain. From the perspective of Chomsky, Fodor, and their followers, it has been assumed that domains constitute large and natural chunks of cognition—language, perception, mathematics, and music. Yet from the expertise literature, it seems that domains might include invented and smaller corners of experience.

Theory Theory

The view that children possess strikingly different thoughts and knowledge from adults is argued most comprehensively by Piaget (e.g., 1953). As is well known to students of cognitive development, Piaget uncovered many surprising childhood errors: Infants seem to believe objects go out of existence when they go out of sight, preschoolers can't conserve and hence apparently believe that amount and weight change when an object's shape changes, and pre-adolescents seemingly can't engage in propositional reasoning. Moreover, as it is generally understood (but see Chapman, 1988), Piaget claimed that certain general cognitive structures (sensorimotor, preoperational, concrete operational, and formal operational stages of thought) underlie children's knowledge and reasoning across a wide variety of content areas. Thus concrete operational thinking uniformly structures such disparate conceptions as number, time, weight, morality, classification, and causal reasoning. Considerable research suggests that Piaget's domain-general stage theory is incorrect, and that cognition seems domain-specific in ways that pose considerable challenges to domain-general theories more broadly (see Gelman & Baillargeon, 1983, for one review).

However, the proposal of qualitative ontogenetic changes in conceptual knowledge has re-emerged in the theory theory—the proposal that children's knowledge is organized into coherent, causal-explanatory systems (e.g., Brewer & Samarapungavan, 1991; Carey, 1985; Wellman, 1990). According to this view, like Piaget's, children have early understandings, but ones that nonetheless differ importantly from adults'. Unlike general stage theories, however, theory theories postulate that these understandings and the changes they undergo are inherently dependent on specific contents and not others. Compare scientific fields such as psychology versus geophysics. Their theories differ fundamentally because their contents differ—the first dealing with behavior, emotion, representation, and learning, the second with planetary forces, plate tectonics, and volcanic activity. Additionally, theories characterize knowledge in ways that go beyond collections of facts. The content of knowledge changes with place and time, so that uncovering what a child in 1994 in Ann Arbor, Michigan, knows about X cannot generalize to a child of 1934 or a child of 2054, or even to a child in 1994 Bombay. As Piaget convincingly argued, the ever-changing details of an inventory of the child's knowledge base may say little about cognitive development more broadly (although they may have important instructional or other applied implications). A focus on everyday theories is an attempt to focus on more enduring and informative knowledge. The aim is a level of analysis that captures structured knowledge systems, as do scientific theories rather than scientific observations.

Beyond a loose use of theories to refer to children's developing knowledge—a usage often adopted even by advocates of expertise and modular accounts—theory theories draw stronger parallels between cognitive development and certain aspects of the development of scientific theories. "Two of the clearest and most impressive instances we have of . . . learning [about the nature of the world] are the acquisitions of children and the achievements of science. . . . The hypothesis of the theory theory is that there are deep similarities between the underlying cognitive mechanisms involved in the epistemological endeavors of childhood and of science" (Gopnik & Wellman, 1994, p. 259). To be clear, the theory theory claim is not that everyday folk, especially children, are doing science. Everyday knowledge is not formalized in explicit canons that are grounded in empirical research; children do not engage in scholarly, scientific reasoning. Instead, the claim is that there are two sorts of theories: everyday and scientific. Everyday theories are coherent systems of knowledge that organize and structure everyday thinking, akin to how theories organize and constrain scientists' thinking. Everyday theories are resistant to change, yet at the same time they are partly grounded in evidence and thus subject to change. Indeed, initial conceptions can give way to radically reorganized conceptions, as is evident in scientific revolutions across history. The essential idea is that initial theory-based conceptions are used by the child to explain, interpret, and make predictions about the world. In this process, initial conceptions encounter theoretical anomalies—facts that don't fit, predictions that consistently fail. At first these anomalies can be ignored, but if they persist, they cause conceptual reorganization and accommodation that lead to revised theories, or in the extreme, to new qualitatively different theories. Just how theory change differs among children versus adults is a matter of some debate. Some suggest that the processes by which children and adults revise their theories are primarily the same (Brewer & Samarapungavan, 1991; Gopnik & Wellman, 1994), whereas others argue that there are important age-related differences (Kuhn, 1989; Klahr, Fay, & Dunbar, 1993).

In contrast to expertise accounts, theory-theory accounts contend that development rarely begins with ignorance; rather, prior systems of concepts constrain and shape learning, beginning with innately evolved strategies or representations for parsing or understanding the world. In contrast to modular accounts, however, theory-theory accounts emphasize initial conceptions that are revisable—via experience and processes of theory change rather than brain maturation alone. Thus, later theories, concepts, and even domains can potentially differ radically from earlier ones.

Summary

In this chapter, we consider children's early understanding of physical, biological, and psychological phenomena. We ask whether—and if so, when and in what fashion—these early understandings form three distinctive domains. In the process, we consider modular, expertise, and theory-theory accounts of the development of foundational knowledge. Currently available research and theory require us to consider some topics in greater or lesser depth, depending on the domain. We begin by considering children's conceptions of physical phenomena, which provide the most comprehensive data concerning infancy. Within this area, we can consider whether foundational, content-full knowledge systems are possible early on, even before the child has language to describe these understandings. We next take up children's understanding of psychological phenomena. By contrasting physical and psychological conceptions, we can consider when in development these represent distinctively different domains—different ontological and causal-explanatory understandings. Moreover, discussion of children's naive psychology has generated the clearest contrasts between theory theory and innate modular accounts of cognitive development. We then turn to biological understandings. Debates concerning understanding of biology again address issues regarding what constitutes a domain, and how one domain might break off from another parent domain developmentally. Moreover, in the case of biological knowledge especially, researchers have raised the question of whether domain-general processes, such as categorization and similarity-based abstraction, might more simply account for children's knowledge acquisition.

NAIVE PHYSICS

Ordinary thought often concerns itself with solid objects and their interactions—rocks falling, balls bouncing, cans stacking, sides containing, and floors supporting. That physical objects exist and have certain predictable properties thus seems foundational to many other conceptions. But this knowledge could be acquired early or later in development. Moreover, the two core framework notions here—physical objects and physical-mechanical causes—are potentially vast in scope. Physical entities include not only solid objects, but unbounded masses (sand and water), gases (air), and the insides and substances of objects; physical causes include not only the dynamics of object contact but also processes like flight, dissolving, combustion, and melting. We focus this section on two primary issues: (a) Descriptively, what kinds of physical knowledge are present in infants and children? Here we start with early infancy, then proceed to later infancy and childhood. (b) Theoretically, how can we best characterize such knowledge, in particular, in modular, expertise, or theory-theory terms?

Early Infancy

Objects

Piaget (1954) concluded that younger infants did not see the world as composed of solid object-like entities. An understanding of the independent existence of objects was instead acquired late in infancy, an insight based on the infant's interactions with objects, especially searching for visible, then invisible, then invisibly moved objects. In the past 10 years, this conclusion has been systematically overturned, both with alternative interpretations of findings using Piagetian tasks (e.g., Bertenthal, 1996; Wellman et al., 1986) and with altogether different methods, such as preferential looking paradigms. For example, Baillargeon et al. (1985) demonstrated that infants as young as 3 and 4 months expect objects to continue to exist when they are out of view. Infants looked longer at a physically anomalous display where a rectangular panel apparently moved right through a solid box than they did at a physically possible event where the panel stopped on contact with the box. This finding suggests that such young infants were puzzled when the screen did not stop on expected contact with the box and thus believed the box continued to exist even when hidden from view behind the panel.

Based on extended findings of this sort (e.g., Baillargeon, 1986; Baillargeon & DeVos, 1991; Spelke et al., 1992), Spelke (1988, 1994) has proposed that very young infants have certain core concepts that constrain their conception and perception of physical objects. For example, physical objects move on paths that are connected (according to the continuity constraint) and cannot move through physical obstructions (solidity constraint). To illustrate, 4-month-old infants were habituated to a display in which a ball was dropped behind a screen, depicted in Figure 11.1 (Spelke et al., 1992). First infants saw the background wall and floor, then a screen covered the display, and a hand holding a ball appeared and dropped it behind the screen. The screen was then removed, revealing the ball at the bottom of the display. After habituation to multiple trials of this event, infants saw a shelf placed in the display in the path of the falling ball. They then saw two contrasting test items where again the ball fell out of sight behind the screen. For the consistent test event, the display was uncovered to reveal the ball on the shelf, consistent with the principles of continuity and solidity. For the inconsistent test event, the ball was revealed in the old position on the floor at the bottom of the display. Four-month-olds looked longer at the inconsistent than the consistent test event, registering enhanced attention if the ball failed to behave in accord with solidity and continuity.

Note that the inconsistent test event is actually most perceptually similar to the habituation presentation—in this case, the outcome is identical, as the ball is shown on the

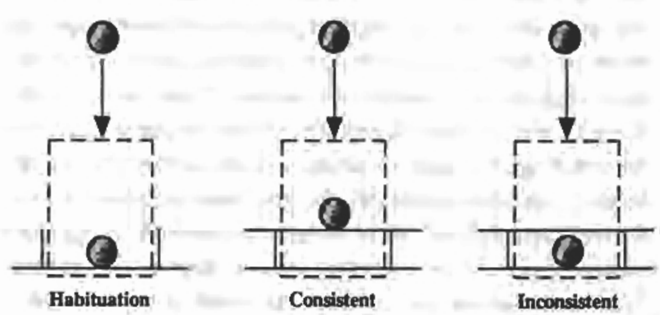

Figure 11.1 Schematic depiction of the habituation and test events used in one of Spelke's studies of infants' knowledge of solidity and continuity. (After "Origins of knowledge," by E. S. Spelke, K. Breingler, & K. Jacobson, 1992, *Psychological Review*, 99, pp. 605–632.

floor at the bottom of the display. In contrast, the consistent test event shows the ball in a novel position on the shelf. If infants are responding on the basis of perceptual similarity or novelty alone, they should look longer at the consistent event because of its greater dissimilarity to the habituation event. However, they look longer at the inconsistent event, suggesting that infants interpret the movements in terms of solidity and continuity, not just perceptual similarity. In addition, note how the study is designed to tap conceptions about objects, not just object perception, in that it assesses infants' expectations about unseen events—the object's unwitnessed path of movement behind the screen. The relation between infant object perception and object conception is theoretically intriguing and also contested—perhaps early object conceptions are induced from earlier perceptual experiences or perhaps they correspond to innate representations of the physical world (Baillargeon, Kotovsky, & Needham, 1995; Bertenthal, 1996; Karmiloff-Smith, 1992; Mandler, 1988, 1992; Spelke, 1994). But studies such as these with hidden objects demonstrate that, at the least, conceptual representations are evident by 3 to 4 months of age.

Physical Causality

Understanding of physical causal forces also seems evident early in infancy. For example, Leslie (Leslie, 1982; Leslie & Keeble, 1987) showed 6-month-olds a film of either one object colliding with and launching a second object, or control events such as a first object making contact with a second one that began to move only after a considerable delay (violating temporal aspects of the causal dynamics). Leslie reasoned that since the control events do not specify causal connections, 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. In several converging studies, Leslie found dishabituation only upon reversing the properly causal sequence, suggesting an early appreciation of at least some aspects of mechanical causation.

Cohen and Oakes (Cohen & Oakes, 1993; Oakes & Cohen, 1990) dispute the age at which infants perceive causality in these displays. In a habituation-dishabituation paradigm, they found that 10-month-olds distinguished between causal and non-causal events, but 6-month-olds did not. Further, when causal agent and recipient varied from trial to trial, even 10-month-olds did not process events as causal in a general way. Also, it is not clear whether infants demonstrate conceptual (vs. perceptual) understanding (Mandler, 1988), since the events are visible in their entirety in these displays. Again, this issue can be addressed in part by assessing infants' understanding of hidden object movements. For example, Spelke (1991, 1994) argues that young infants understand several principles that define the nature of simple mechanical causation, especially contact and no-action-at-a-distance: "objects act on each other if and only if they touch" (Spelke et al., 1995, p. 49). To test these understandings, infants were first habituated to one object moving behind a screen and another object emerging from behind the same screen at the other side. After habituation, the infants were shown two test sequences with no screen. In the consistent event, children saw the first object move up to and contact the second object, thereby launching its movement, consistent with the principle of contact. In the inconsistent event, they saw the first object go toward but not touch the second object, which then moved off on its own. Even 6-month-olds looked longer at the inconsistent event (Spelke & Van de Walle, 1993; Van de Walle et al., 1994), evidently inferring that the two objects met behind the screen during habituation and thus being surprised to see the no-contact test event. Kotovsky and Baillargeon (reviewed in Baillargeon et al., 1995) provide additional demonstrations of infants' appreciation of the role of contact in causing physical movements.

Developments Later in Infancy

Suppose we grant that young infants represent objects as continuing to exist, as moving due to contact collisions, and as moving along continuous paths even when out of view. What other basic object understandings might there be, and when do they appear? Spelke argues that, although an understanding of solidity and contact appears early in infancy, an understanding of such physical notions as gravity and support appear only later in the first year. Thus, in an experiment analogous to the one depicted in Figure 11.1 (Spelke et al., 1992), 4-month-olds were habituated to a hand releasing a ball behind a screen, which was then removed to show the ball at rest on a shelf suspended above the floor of the apparatus. For the test events, the shelf was removed. In the consistent test event, infants saw the hand release the ball behind the screen, then when the screen was removed, subjects saw the ball at rest on the floor of the apparatus. In the inconsistent test event, when the screen was removed, the ball was revealed in the same position it had occupied during habituation—but, with the shelf now absent, the object appeared to float in midair. Four-month-olds looked equally at these two test events; only older infants looked longer at the inconsistent event. Thus, 4-month-olds in the original experiment seemed surprised if the ball appeared to pass through a solid shelf, but in a parallel situation, were not surprised if it appeared to be suspended without support against gravity.

Another later development seems to be the capacity to reason quantitatively about events which previously were understood only qualitatively (Baillargeon, 1994). For example, 4-month-olds represent an occluded object as continuing to exist when out of sight, but it is not until several months later that they represent just how big that occluded object is (e.g., its height).

In the sorts of studies reviewed thus far, infants individuate different objects in terms of spatio-temporal cues (these two things are spatially separate, so they must be two objects) and movement cues (object X moving on path A cannot be object Y that is moving on path B). Indeed, infants can keep track of whether there are 1, 2, or 3 different objects in a display, apparently forming some kind of numerical count (e.g., Antell & Keating, 1983; Starkey, 1992; Wynn, 1992). But how do infants individuate and represent objects more precisely? Adults understand not only that each object is spatially distinct from other objects and that objects move through space on distinctive paths, but also that identity and property information individuate objects. If I see a car at one time and place, A, and then later see the identical car, down to its distinguishing dents and marks, at another time and place, B, I assume I have encountered the same car even though the two instances are separate in space and even without knowledge of the spatial movements that would bring it from A to B. In contrast, if I see a green car go into a short tunnel and a red one emerge on the exact spatio-temporal trajectory as the first, I would probably assume there are two cars in spite of the continuous path of movement from one to the next. It is possible, however, that young infants ignore property information.

Recent research by Xu and Carey (1996) illustrates this point. Suppose adults are shown a display with an occluding screen and see one object (a toy rabbit) emerge from one side of the screen and then return, alternating with a different object (a cup) emerging and returning from the other side. Adults infer there must be two objects behind the screen. Note that, in terms of spatio-temporal movements alone, it is equally possible that: (a) there are two objects, or (b) a single object unspecified as to property features of any sort is emerging first from one side then from the other. Property/identity features (cup vs. rabbit) automatically specify to adults that there are two objects, sharing in some way common spatial trajectories, but do young infants have the same conception? Indeed, if infants look to movement rather than properties to individuate objects, they should not know if there are one or two objects behind the screen; the movements alone do not specify one or two objects, only the properties do. In a set of experiments, Xu and Carey (1996) presented infants with variations on this demonstration, showing them a series of screened emergences, then testing the infants' conceptions by raising the screen and showing them displays of one or two objects. Ten-month-olds were able to use spatiotemporal information but failed to used property/identity information to represent distinct individual objects. However, 12-month-olds, like adults, individuated objects in terms of property/kind information. In essence, the younger infants were unsurprised to find either one or two objects when the screen was raised, though perfectly able to keep track of one versus two objects in analogous hidden displays using movements to individuate the objects.

Relatedly, as Gopnik and Meltzoff (1997) point out, 5- and 6-month-olds will track the trajectory of an object that disappears behind one side of a narrow screen, then emerges at the other side (e.g., Bower et al., 1971; Meltzoff & Moore, 1995; but see Gratch, 1982, or Muller & Aslin, 1978, for failures to replicate). These younger infants will not show disrupted tracking if one object disappears and a completely different one emerges, as long as the spatio-temporal path is continuous (Bower, 1982; Meltzoff & Moore, 1995; Moore et al., 1978). In short, these data suggest that late in the first year of life, infants' object concepts may undergo a change, with infants first coming to distinguish objects, as adults do, on the basis of property/kind information. It is not that before this time infants fail to discriminate between objects that look different; they do (e.g., Cohen & Younger, 1983). However, such property features do not mark identity for younger infants, in the sense of specifying distinctive individual objects that continue in time and space.

Older Children

Objects

Toddlers and preschoolers, like infants, expect objects to continue to exist and to move on continuous paths. Toddlers regularly solve search problems requiring them to understand that objects continue to reside in a location even when nonvisible (see e.g. Sophian, 1984). For example, if an object is hidden under a cover, 18-month-olds will search for it there and be surprised if they find not the original object, but a different one (LeCompte & Gratch, 1972); indeed, they will continue to search for the original object. In invisible displacement tasks (in which an object is first hidden in a container which is moved to several locations, then shown to be empty), toddlers logically work out where the object must be, given the movement of the container and the object sightings (e.g., Haake & Somerville, 1985). Toddlers will display an object at the bottom of a cup-like cylinder to someone else by holding it so that the other can see the object—thereby making it invisible to themselves (Lempers, Flavell, & Flavell, 1977). They regularly use words to comment on the existence of out-of-sight objects, their comings and goings ("all gone"), their locations and identities (e.g., Gopnik, 1984).

Not all understandings of objects, however, concern existence, solidity, paths, and appearances. Indeed, it could be argued that such aspects concern the outer, phenomenal, apparent aspects of objects. Adults appeal as well to a variety of less obvious features and underlying constructs to explain and make sense of the physical world—for example, an object's center of balance, its molecular composition, or its inner working parts. Recent evidence suggests that quite young children begin reasoning about such unobservable physical constructs. Consider children's understanding of the insides of objects, such as the gears of a watch or the bones of an animal. Insides are often unobserved (though in principle observable), but they are often particularly important for understanding what items are and how they function (e.g., the gears of a watch vs. its glass crystal). 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" (R. Gelman, 1990; Simons & Keil, 1995). 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" (S. 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. Similarly, children may report that since all watches are similar, their insides are similar. However, in a different sort of task, S. Gelman and Wellman (1991) asked children to reason about triads in which internal similarity did not correspond to external similarity, for example, triads such as an almond, a very similar-looking rock, and a dissimilar-looking peanut. 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 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, whether an egg would still be an egg, or a watch still a watch, if its outside (shell or glass) versus insides (white and yolk, or gears and other parts) were removed, 4- and 5-year-olds affirmed that insides were more essential than outsides. Other demonstrations suggest that young children's understanding of objects depends on conceptions of kinds, not just on perceptual similarities.

Objects like watches not only have distinct insides and distinct structural identities, they are also composed of material substances such as metal and glass. Smith et al. (1985) showed that 4-year-olds understand that various kinds of objects 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) 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 children were asked whether each item 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 appear to have a conception of structured objects, but also a conception of the substances out of which physical objects are composed. Moreover, Kalish and Gelman (1992) found that children appropriately draw different kinds of inferences based on material substance versus object kind. They report, for example, that wooden pillows are hard and glass frying-pans break—even though they had never before encountered a hard pillow or a breakable frying pan.

Unlike watches and eggs, objects such as a wooden pillow or a sugar cube are homogeneous substances throughout, all of one physical kind, such as wood or sugar. Au (1994) studied children's conception of such substances. Children between the ages of 3 and 8 years were shown chunks of a variety of natural and artificial substances (e.g., wood vs. playdough) with familiar and novel names (e.g., wood vs. carbonate). Children were then shown these substances transformed in three ways: (a) large chunks broken into smaller chunks, (b) chunks turned into powder, and (c) powders dissolved in water. Note that transformations of type (a) change size but not appearance. Type (b) transformations change size *and* appearance in the sense of texture and feel. Type (c) transformations change appearance in the extreme sense of making the substance invisible. Children correctly asserted that the items still had the same names and were still of the same stuff under these transformations. Transformations of type (c) were most difficult, but even 3-year-olds were 65% to 70% correct on these questions. In another study, children were asked questions about the properties of the substances. Some properties were material-relevant, such as what the substance would taste like, or how it would react to heat (e.g., melt vs. turn black in a hot oven); some properties were object-relevant but material-irrelevant, such as size (fit into a matchbox) and weight. Young children were again largely correct, appropriately distinguishing between material-relevant and irrelevant properties for most items and transformations.

These data show that even quite young children know that larger objects are composed of smaller pieces and these pieces, even if invisible, have enduring physical existence and properties. Au et al. (1993) and Smith et al. (1985; Carey, 1991) suggest that these insights constitute the basis of a naive atomic theory of matter, wherein everyday objects are, in the final analysis, composed of tiny bits of matter.

Consider further the distinction between chunks and powders presented above. Ontologically, physical entities are divided into solid bounded objects that have form and individuation versus aggregates or unbounded masses (water, piles of sand) that do not (Keil, 1979; Sommers, 1963). Young children know that both are physical entities—4-year-olds judge it is impossible for water to fill a box that is already filled by a steel block (Carey, 1991). At the same time, Soja et al. (1991) demonstrated that 2-year-old English-speaking children appreciate that solid physical objects differ from massed aggregates in terms of their distinctive properties and ontological status. This conceptual distinction is in place prior to children's linguistic mastery of mass versus count nouns in language.

Physical Causality

The above studies demonstrate that quite young children understand much about physical objects and reason about them in terms of underlying constructs and properties, beyond just their surface features. Equally important are children's conceptions of and inferences about the causal interactions that determine object movements and transformations. Following Hume, causal inferences might be construed solely in terms of content-independent logical principles. Causes 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 on the basis of covariation. One conclusion of such research concerned preschoolers' consistent failures to reason causally in these logical ways (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 causal events. Specifically, a Humean analysis fails to consider the attribution of causal powers, that is, the force or source that actually generates its effect. In physical systems in particular, we reason about specific mechanisms whereby some cause produces some effect by transmitting a force or blocking such a force (Bullock et al., 1982; Cheng, 1993; Shultz, 1982). If knowledge about physical objects and physical causal mechanisms constitutes a domain of understanding, and if children early on acquire a rich understanding of that domain, then they should make appropriate causal inferences in that domain, even if their logical reasoning in other domains is limited.

Bullock et al. (1982) addressed this issue by demonstrating that preschool children consider intermediate mechanisms—not just input-output correlations—to make predictions about causal events. For example, in one study, children were presented with a domino-like array consisting of a series of blocks, each of which caused the next to topple. 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. Even 3-year-olds accurately predicted which modifications to the device would be relevant to how it worked (e.g., removing intermediate blocks) and which would be irrelevant (e.g., using a glass vs. wooden rod).

Similarly, Shultz (1982) found that preschool-age children reason sensibly about several sorts of causal transmissions.

In several ingeniously controlled situations, preschoolers appropriately 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—despite competing Humean cues. The spotlight effect, for example, was instantaneous, rather than obviously prior in time, and involved no mechanical-spatial contiguity. Shultz thus claimed that young children figure out specific causal mechanisms and often reason properly about them, rather than deduce causes from raw patterns of temporal sequence and covariation. (See Cheng, 1993, for a related analysis but a revised account of these experiments.)

Goswami and Brown (1989) considered the possibility that, with respect to physical causality, young children (3–6 years) might be able to engage in sophisticated, 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 appears 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 isolated facts (bird: air :: fish: ?)—not physical causal mechanisms that children may understand well. Goswami and Brown (1989) first tested 3- to 6-year-olds' understanding of such familiar causal acts or transformations as cutting 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 and Brown tested children's ability to reason analogically about such relations such as, Playdoh: cut-up Playdoh :: apple: ?. After being presented with 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 were significantly correct on these sorts of problems. Goswami and Brown conclude that "as long as the child understands the causal relation, he or she can solve an analogy based on that relation" (1989, p. 79). Goswami (in press) further articulates and reviews recent empirical evidence for this claim.

Although these studies emphasize early developmental achievements, we do not wish to imply that children's causal understandings are wholly accurate. Indeed, even adults hold some persistent misconceptions. Consider the literature on understanding of object dynamics in children and adults (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 the movement of colliding balls. These studies show that adults' naive understanding of such motions is coherent (McCloskey, 1983), although often in error. Proffitt and Kaiser conclude that even children are relatively competent with simple problems in which motion and force transmission involve essentially simple symmetrical objects whose action can be adequately seen in terms of a single particle of mass (Proffit et al., 1990). 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 people's 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 find that even very familiar events may be completely misunderstood.

How to Characterize the Physical Domain

What might account for these early achievements and developments in physical understanding? On an expertise account, even infants may rapidly learn about physical phenomena because the world is full of objects that all obey core principles; hence even 4- and 5-month-olds could have received massive amounts of experience sufficient to develop early expertise in these matters. Spelke argues, however, that this early knowledge is innate (e.g., Spelke, 1994). In part, her argument is logical—how could infants learn about object movements at such an early age if they do not single out objects for consideration to begin with? But there are also empirical arguments. For example, since all objects cast shadows, infants have been exposed to massive amounts of experience with shadows as well. If experience leading to expertise determines infants' understanding of objects, one might expect infants to be similarly expert at the nature and behavior of shadows. Note, however, that shadows do not conform to the core principles used to understand objects. Shadows are not solid and they embody action at a distance—if the light source at a distance moves, so does the shadow; thus, it is not launched by contacting objects. Spelke and her colleagues (Spelke et al., 1995) have shown that 5- and 8-month-old infants misconstrue shadows. It is not just that infants are ignorant about them; instead, apparently, they expect them to act like objects. Infants' early, correct construal of objects, but not shadows, poses a challenge for an expertise approach.

One possible account of such findings is to posit the existence of an early developing module dedicated to understanding solid objects and at first misapplied to related entities (such as shadows). Leslie (1987, 1994) proposes the existence of such a module, and Spelke (1994; Carey & Spelke, 1994) argues for something like this in characterizing initial knowledge of objects as innate and domain-specific. In principle, there are strict limitations on the modifiability of innate modules over development. Therefore, Spelke distinguishes between core physical concepts (such as solidity and contact) that appear early and with minimal input, and noncore physical concepts (such as gravity) that appear later and require more extensive experience. Spelke suggests that infants' core principles persist into and throughout adulthood. These early beliefs are foundational in that they define an immutable core of physical knowledge, always constraining what will be selected as entities for further consideration.

Other researchers, however, advance different accounts, ones that provide a bigger role for learning and development in a basic understanding of objects themselves. For example, Cohen (1988) outlines an information-processing account of infant cognition, and Baillargeon et al. (1995) contends that infants begin not with innate knowledge, but with a domain-specific learning mechanism. Differential experiences result in different kinds of learning; this process, rather than core versus noncore knowledge, shapes development.

Baillargeon has examined infants' understanding of various physical phenomena: collisions, containment, occlusion, and so on. At a broad level, her empirical results are in accord with those summarized thus far (e.g., Baillargeon et al., 1995). However, Baillargeon argues that infants' understandings emerge in a precise sequence that does not fit Spelke's account. Consider Spelke's claim that infants are born with the core belief that objects are solid, but that infants must acquire noncore beliefs, such as those about support, via observation and learning. "One prediction suggested by this distinction is that core principles would be demonstrated earlier than non-core beliefs, and would be revealed uniformly in all situations in which they are implicated" (Baillargeon, 1994, p. 112). According to Baillargeon's recent research, however, even 3-month-olds understand certain aspects of support, hypothesized by Spelke to be a later-developing, noncore belief. Perhaps more telling, Baillargeon argues that such things as barrier phenomena (that solid barriers are obstacles to objects and mechanical forces), passing-through phenomena (that in the absence of a barrier, object and forces can pass through space), and containment and veiling phenomena (that one object can be concealed by another object in the same space by being contained or covered by it) should all reveal a general understanding of object solidity, *if* infants possess such a core concept. But, she contends, infants learn about some of these phenomena long before others. Thus, according to Baillargeon et al. (1995), the pattern of infants' successes and failures at a young age does not suggest the presence of a general core principle such as that objects are solid. Instead, infants "go about the world identifying basic ways in which objects behave or interact. These types of interaction are akin to conceptual roles, i.e., infants reason about objects and occluders, objects and gaps, objects and supports, objects and barriers . . ." (p. 113). These concepts are initially quite separate. They speculate:

> Three-month-old infants have already learned that objects fall when released in mid-air . . . because this expectation is consistent with countless observations (e.g., watching their carers drop peas in pots, toys in baskets, clothes in hampers) . . . Infants do not begin to recognize what type of contact is needed between objects and their supports until 4.5 months . . . because unilateral visually guided reaching emerges at about 4 months. . . . With this new-found ability, infants may have the opportunity deliberately to place objects against other objects, and to observe the consequences of these actions . . . It is not until 6.5 months that infants begin to appreciate how much contact is needed between objects and their supports because . . . the ability to sit without support emerges at about 6 months of age; infants then become able to sit in front of tables . . . relieved from the encumbrance of postural maintenance and thus free to manipulate objects. (pp. 110–111)

In short, as the infants' motoric abilities emerge, their experience of the world changes and their object understandings follow suit.

This sort of developmental scenario is similar in form to one advanced by Campos and Bertenthal with regard to infants' understanding of space and distances, especially as indexed by their fear of heights (e.g., Bertenthal & Campos, 1990; Campos et al., 1978). They claim that self-produced locomotion—rather than age—critically advances the infant's understanding and induces a wariness of heights. This hypothesis is supported by systematic studies in which infants are given early locomotor experiences via wheeled walkers (Campos et al., 1992). Similarly, Bushnell and Boudreau (1993) argue that infants' understanding of objects from haptic exploration develops in a sequence that is best explained by developmental changes in abilities to control the hands and fingers.

Do infants' early conceptions of objects undergo radical changes when developing into adults' and older children's conceptions, or—as Spelke maintains—does infants' initial knowledge remain intact as the unchanging core of adult knowledge? On this difficult question, Carey (e.g., 1991) and Gopnik and Meltzoff (1997) propose that there are radical conceptual changes in the child's basic understanding of objects, and they interpret these changes in theory-theory terms. Consider the change, noted earlier, from individuating objects in terms of spatial coordinates and movement alone to using property features to do so. It could be argued that, for adults, identity or property information is more important than spatial information for tracking and identifying individual objects. In contrast, Gopnik and Meltzoff (1997), following Bower (1974), suggest that babies reidentify objects by their movements *rather than* their properties. If children undergo this developmental shift, it would surely qualify as a radical conceptual reorganization, one that directly affects conceptions of identity, individuation, and sameness. Adults who tracked objects by path of motion rather than featural cues—believing that an object could enter a tunnel as a duck and come out of it as a ball, for example—would be so unlike normal adult humans that they might indeed constitute examples of the metaphorical alien considered at the beginning of this chapter.

Likewise, consider again children's conception of material substance. Carey (1991) and her colleagues suggest that preschoolers have a conception of material substances (as reviewed earlier), but that in addition, children's understanding of matter and substance changes profoundly beyond the preschool years. Like adults, young children judge that large chunks of styrofoam are made of small bits of styrofoam. But unlike adults and older children, preschool children judge that visible pieces of styrofoam weigh nothing at all. Thus having weight, having matter, and occupying space may not be coextensive aspects of objects for young children as they are for adults—implying that children's conception of objects undergoes an important conceptual revolution.

The theory-theory position is supported not only by evidence of radical changes with age, but also evidence of coherence among children's beliefs—especially when such coherence demonstrates a mismatch with the input children are receiving. Thus, note that young children's reasoning about physical objects and physical-mechanical systems of the sorts reviewed above coheres in several important ways. Coherence is evident when children make novel inductive inferences (Au, 1994), when they reason analogically (Goswami, in press), and when they maintain sensible yet incorrect beliefs—at times even in the face of instruction. For example, according to Au's research, children believe that substances are homogeneous throughout—sugar in cubes is composed of sugar particles, which are composed of still smaller particles, and so on. Every bit of sugar is composed of still smaller bits of sugar. At the extreme, however, this homogeneous conception of matter becomes incorrect. At some point when sugar is broken down into smaller and smaller bits, the smaller pieces would be hydrogen, carbon, and oxygen pieces, not sugar. A scientific understanding of matter is particulate—in terms of fundamental particles of matter—not homogeneous in terms of substances. Of course, a homogeneous conception is adequate for and consistent with everyday observations. When children are taught the scientific particulate theory, however, they have difficulty mastering it, and maintain instead an everyday homogeneity view; some students insist on the homogeneity view even when they take chemistry courses in college (Gabel & Samuel, 1987; Novick & Nussbaum, 1981).

In a similar vein, Vosniadou and Brewer have studied children's understanding of everyday astronomy (Vosniadou, 1989, 1994; Vosniadou & Brewer, 1992, 1994): conceptions of the earth's shape (flat or round), the movement of the planets, and so forth. Conceivably, children could just learn from their elders the relevant facts. However, children's understanding reveals the imprint of their larger coherent theories of physical objects. In spite of being told that the earth is round, most young children at first believe the earth is flat, consistent with their everyday observation of the physical earth stretching before them as a relatively flat plane and their everyday notions of support (if the earth were spherical, people on the bottom would fall off). These coherent notions are specially visible in the numbers of children who assert that the earth is round, consistent with received instruction, but then go on to explain that it is round like a pizza, or that it is round like a large shallow bowl, with all the people safely on the inside and the sky above. Vosniadou and Brewer's studies demonstrate the coherence of children's physical beliefs by showing their conceptual systematicity even in cases where children's conclusions are wrong, at odds with, or only partly adjusted to adult beliefs and input.

Conclusions

Certain core beliefs about the nature and causal interactions of physical objects appear to constitute early foundational human knowledge, emerging in infancy and rapidly becoming enriched to include a deeper understanding of objects (for example, support and gravity), as well as later understanding of insides, of substances, of planetary systems, and more. Conceptions of physical objects also appear to change more profoundly, for example, by undergoing revisions to include property/kind object identification. In the extreme, in some persons at least (e.g., expert physicists), conceptions become reorganized into systems involving such sophisticated concepts as fundamental particles (quarks), space-time continua, and matter-energy interchangeability. Before drawing conclusions regarding the modular, expertise, and theory-theory positions as explanations for such changes, we examine the domains of psychology and biology.

NAIVE PSYCHOLOGY

Naive psychology focuses on our everyday understanding of psychological states and experience. It is thus one aspect of social cognition (Flavell & Miller, this Volume), a topic that includes understanding of social relationships such as kinship, social groups such as families, social institutions such as schools and governments, and social conventions such as manners and morals. Philosophers, ethologists, and psychologists have increasingly argued that naive psychology is a specially evolved human competence, a distinctive everyday theory, a foundational system of human thought (Cheney & Seyfarth, 1990; Churchland, 1981; Dennett, 1987; Humphrey, 1993; Povinelli, 1993; Wellman, 1990). Moreover, for adults, psychological reasoning seems to contrast quite starkly with physical reasoning. Rocks, centers of gravity, and melting are all quite different from emotions, minds, and dreaming.

Research on children's developing psychological understanding has mushroomed in the last 10 to 15 years under the rubric of the child's theory of mind, a phrase first introduced by Premack and Woodruff (1978) to question whether chimpanzees share with us a mentalistic understanding of purposeful actions. We divide our discussion of naive psychology into two parts, first by considering the understanding of verbal children age 3 years and older, and second by taking up similar questions regarding infancy. In each of these parts, we consider (a) what kinds of psychological knowledge are present in children, and (b) how to characterize that knowledge. A further question of special import concerns whether psychological understandings form a distinctive conceptual domain for young children, separable from other potential domains. This question—and the parallel question for children's understanding of physical phenomena—can be addressed by comparing physical and psychological conceptions with one another. For example, do children make a fundamental ontological distinction between physical objects (e.g., a rock) and psychological entities (e.g., a thought about a rock)? Do children distinguish and reason differently about mechanical and psychological causation?

Preschoolers

Mental Entities

When Piaget argued that preschoolers were realists, he was claiming, in part, that they do not honor a distinction between mental and physical phenomena and hence think of mental entities as tangible, physical ones: "The child cannot distinguish a real house, for example, from the concept or mental image or name of the house" (Piaget, 1929, p. 55). In contrast, current research demonstrates that children as young as 3 years firmly distinguish the mental and physical worlds. These studies use more precisely constructed judgment tasks, rather than relying on interpreting young children's often cryptic responses to open-ended interview questions. For example, if told about one boy who has a dog and another one who is thinking about a dog, young children correctly judge which dog can be seen, touched, and petted (Harris et al., 1991; Wellman & Estes, 1986). Moreover, if told about someone who has a dog that ran away and about someone who is thinking of a dog, they 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). Even if asked to consider certain specially vivid mental entities, such as a mental image of an object depicted by a thought bubble, 3-, 4-, and 5-year-olds still distinguish mental phenomena appropriately from comparable physical objects, such as a picture of an object hidden in a box (Estes et al., 1989; Wellman et al., 1996). By 3 years of age, young children also understand something of the subjectivity of thoughts. In appropriately simple tasks, they are able to state, for example, that while they think a particular cookie tastes yummy, someone else could think it's yucky, or that while Mary thinks a particular box has a doll in it, Bill thinks it contains a teddy bear (e.g., Flavell et al., 1990).

Psychological Causes and Explanation

Adults' psychological understandings arguably constitute a specific system of causal-explanatory reasoning. A useful shorthand description of this system is to characterize it as a belief-desire reasoning framework (D'Andrade, 1987; Fodor, 1987; Wellman, 1990). According to this analysis, at the center of our everyday psychology is a basic triad: beliefs, desires, and actions. Why did Jill go to the swimming pool? She *wanted* to swim and *thought* the pool was open. The fundamental, albeit common idea is that people engage in actions because they believe those actions will satisfy certain desires. Everyday psychology builds on this basic infrastructure in a variety of ways. For example, it encompasses reasoning such as: Why did John go to the candy machine? He was hungry and wanted a candy bar, and thought he'd seen the kind he liked in that machine; boy, will he be surprised. That is, naive psychology incorporates beliefs, desires, and actions centrally, but also a network of related constructs such as physiological states (e.g., "he was hungry") that ground one's desires, and perceptual experiences (e.g., "he'd seen that kind") that ground one's beliefs. Furthermore, actions lead to outcomes in the world, and these outcomes lead to emotional reactions, such as surprise, happiness, sadness, anger.

Note that under this characterization, psychological reasoning involves a coherent system of constructs, and depends on appeals to unobservable mental states. Individual phenomenal experiences are arguably directly experienceable in ourselves (e.g., my longing for that chocolate bar), but we attribute unobserved mental states to others as well as to self. Moreover, beliefs, desires, actions, emotions, and so on are intertwined. Because an actor has certain beliefs and desires, he or she engages in certain intentional acts, the success and failure of which lead to emotions, revised beliefs, renewed desires, and so on. Such a system of reasoning seems notably different from the one used for physical reasoning, which relies on mechanical causes, physical forces, contact, and solidity.

If preschool children are asked to explain simple human actions (e.g., Jane is looking for her kitty), they, like adults, predominantly advance belief-desire explanations (she wants her kitty, she thinks the kitty is missing). They do so in laboratory situations (Bartsch & Wellman, 1989; Wellman & Banerjee, 1991) and in everyday conversations (Bartsch & Wellman, 1995; Dunn & Brown, 1993). Stein and Trabasso, among others, have systematically shown that 3-, 4-, and 5-year-olds are quite good at understanding the psychological causality depicted in simple stories about human characters who want certain goals, possess certain beliefs, use the information in their beliefs to execute certain plans to overcome obstacles to their goals, and are appropriately happy or sad or angry when they have attained or failed to attain these goals (Stein, 1988; Stein & Trabasso, 1982; Trabasso & Nickels, 1992; Trabasso, Stein, & Johnson, 1981).

By 3 or 4 years, children's psychological understandings also form a coherent system of interrelated constructs. In their explanations, young children reason backwards from actions to beliefs and desires, and can do so in prediction tasks as well (Robinson & Mitchell, 1995). They can also reason forward from characters' beliefs and desires to predict their actions, emotions, or statements (e.g., Hadwin & Perner, 1991; Harris et al., 1989; Wellman & Bartsch, 1988; Wimmer & Perner, 1983). At this age, children also know that perception informs beliefs (Pillow, 1989; Pratt & Bryant, 1990; Wimmer et al., 1988) and something of how various sources of information shape distinctive mental states (O'Neil & Gopnik, 1991; Woolley & Bruell, 1996). Moreover, they conceive of emotions as subjective states (Wellman et al., 1995), understand that emotional reactions are dependent on other mental states such as goals and intentions (e.g., Stein & Levine, 1989; Yuill, 1984), and even understand that some emotions (e.g., happiness) are more dependent on desires whereas others (e.g., surprise), are more dependent on beliefs (Hadwin & Perner, 1991; Wellman & Banerjee, 1991). Again, some of the most telling demonstrations of children's ability to follow and to construct coherent psychological accounts come from their abilities to comprehend and create narratives (e.g., Stein & Albro, in press). Moreover, young children's use of mental terms demonstrates an interlocking network of related constructs. When asked to explain the nature of mental entities, children—like adults—do so in terms of other mental constructs: about a dream, "it's only pretend"; about a false memory, "he's imagining it"; about a mental image, "I could only touch it with my dream hands" (Wellman, 1988). By age 3 or 4 at least, it can be argued that children's naive psychology, like adults', reveals much of the character of a naive framework theory.

Consequently, as early as 3 years, children appropriately distinguish psychological from physical causes and explanations. By 3 years, many children report 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). Children 3 and 4 years old precisely distinguish thinking from doing, one as internal, private, and "just" mental, the other as overt, public, and physically consequential (e.g., Flavell et al., 1995; Wellman et al., 1996). Even in their understanding of human action and movement, 3- and 4-year-olds can distinguish sharply between psychological versus physical causes. Human movements can be object-like (e.g., being blown by the wind) and hence explainable in physical causal terms, or they can be voluntary (e.g., desiring and deciding to go outdoors and doing so) and hence explainable in belief-desire terms. Early in the preschool years, children make such explanatory distinctions (Schult & Wellman, in press).

Much of the above analysis depends in part on granting young children an understanding of a variety of mental states, such as beliefs and desires. Developmentally, however, several researchers claim that children understand some of these states—in particular desires, emotions, and perceptions—before others—notably beliefs. For these and other reasons, children's understanding of beliefs has received special research attention. False beliefs have been investigated especially intensively because false beliefs neatly contrast with reality itself (e.g., Jane believes it is raining, but it is not).

Many studies now show that by 4 and 5 years, children reason competently about false beliefs at least in clear, simplified situations. For example, if children of this age are shown a distinctive candy box that actually contains pencils, they can correctly predict that a naive viewer of the box will falsely believe it contains candy, not pencils (Gopnik & Astington, 1988; Perner et al., 1987). Or, if 4- and 5-year-olds see a person notice where an object is placed, and then see that the person is absent and thus cannot observe when the object is moved to a new location, they can accurately predict that the person will mistakenly look for, and falsely think that, the object is in the original location (Avis & Harris, 1991; Moses & Flavell, 1990; Wimmer & Perner, 1983). Intriguingly, although 4-year-olds often pass these sorts of false belief tasks, in many studies, younger children, typically 3-year-olds, fail them. In this, 3-year-olds do not just answer randomly or confusedly, they make a specific error. For example, they say that the other person will think that the box contains pencils, or that the person will look for the object in the new, correct location. That is, they predict the other's action and they attribute to the other thoughts based on objective reality rather than the person's subjective beliefs. This developmental difference from 2 or 3 to 4 or 5 years has been found with a variety of tasks and methods—when the questions are about mental states directly or when they are about behavior (where the person will search or look), when the target person is a story character, a videotaped character, a puppet, a child, or an adult, and even in tasks that focus on the child's own beliefs.

These findings, among others, lead to the developmental hypothesis of a major reorganization in children's naive psychologies in the ages from 2 to 5. According to this hypothesis, younger children construe persons as relating to the world directly as it is (or at least as the child himself believes it to be), whereas older preschoolers construe people as relating to the world through their representations of it. To be clear, it is *not* that children below age 4 lack a naive psychology; several lines of research suggest that very young children have a clear understanding of some mental states. The claim is that this early understanding is different from the representational understanding of older children and adults.

How to Characterize Preschoolers' Psychological Understandings

Theory-theory, modular, and expertise accounts provide alternative characterizations of these psychological conceptions and developments. Theory-theory accounts characterize preschool children as proceeding from an earlier simple desire (Wellman, 1990), situational (Perner, 1991), or "connections" (Flavell, 1988) theory of mind to a later representational theory. Gopnik and Wellman (1994) claim that young children's psychological understandings are demonstrably theory-like in that unobservable theoretical constructs—such as beliefs and desires—are evident in how children explain and predict human behavior and states, and in their theory-based interpretation of evidence. For example, 3-year-olds not only fail to attribute false beliefs to others, they similarly fail to understand their own false beliefs and misinterpret their own psychological states (Gopnik, 1993). Moreover, the process of developmental change—from understanding of desires and emotions but not beliefs, to understanding of beliefs but still explaining behavior only in terms of other states, to only later incorporating an understanding of beliefs into psychological explanations—closely mimics a process of theory change. According to this account, a conception of belief is first absent, and then developed only as a marginal auxiliary hypothesis, before becoming theoretically central to children's understanding.

In contrast, a nativist, modular account of the same data is advanced by theorists such as Fodor (1983, 1992) and Leslie (1987, 1994). Fodor's claim is that naive psychological understanding is designed into the human conceptual apparatus by evolution, that it necessarily encompasses an understanding of both beliefs and desires, that such an understanding is present extremely early in life, and that it requires little, if any, learning. Such a position leads to questions regarding the data purporting to show that understanding of beliefs is absent in 3-year-olds and emerges only in 4- and 5-year-olds. Several studies now show that at least in some situations 3-year-olds, too, perform correctly on false belief tasks. In several studies, downplaying the salience of the real state of affairs (e.g., that the candy box contains real pencils, not candy) or making salient the prior mental state (e.g., that the child first thinks it is a candy box) helps young children correctly identify the character's false belief (Mitchell & Lacohee, 1991; Woolley, 1995; Zaitchik, 1991). In addition, 3-year-olds at times perform well if they are more actively engaged in deceiving the target person (Chandler et al., 1989; Sullivan & Winner, 1993; but see Sodian, 1994), if the key features of the false belief narrative are overlearned (Lewis et al., 1994), or if certain ways of phrasing the false belief question are used rather than others (e.g., Lewis & Osborne, 1990; Siegal & Beattie, 1991).

The data have also fueled proposals that understanding belief specifically, and developing belief-desire reasoning more generally, are due to increasing expertise (e.g., Dunn, Brown, & Beardsall, 1991; Siegal, 1991; Stein & Trabasso, 1982). One of these expertise accounts—simulation theory—deserves special mention because it is uniquely domain-specific. As described thus far, children possess mental state representations that function like theoretical constructs, allowing children to interpret behavior in intentional terms by attributing to themselves and others mental states such as beliefs and desires, and thereby to predict and explain actions, understand others' minds, and so on. Even modular theorists such as Fodor (1992) adopt this sort of basic characterization. In contrast, simulation theory contends that ordinary reasoning about persons and minds is instead based on our own first-hand experience of mental life (Goldman, 1992; Gordon, 1986; Harris, 1991). Since we are creatures possessing mental state experiences, we certainly come to refer to states such as beliefs and desires, but our capacity to do so does not depend on developing concepts and theories of such states. Rather, we simply experience and report our own mental experiences. Attributing such experiences to others, relatedly, proceeds not via a series of conceptual inferences but instead via a process of simulation. To think about others' minds, we project ourselves into the other person's situation, imaginatively consider what we would experience in that situation ourselves, and then attribute that (simulated) experience to the other.

Expertise is needed in this process because children must learn not to attribute their own states to others, but to simulate others' states from information about their situation. According to Harris (1992), who has articulated a simulation account in most detail, children's simulations operate against a backdrop of two default settings, namely the mental states of the self and the real state of the world. Simulations are more or less difficult depending on how many defaults the child must override. To simulate someone else's desire or belief, for instance, one must ignore one's own state and imagine the state of the other. Suppose a child does not know what is in a box, but thinks it holds a doll. To simulate the belief of someone who thinks it holds a toy truck, the child must override his own belief and simulate the other's contrasting belief. An understanding of false beliefs, however, requires the child to override not only her own mental stance, but reality as well. Thus, if the child knows the box holds a doll and must simulate the thought of someone else who mistakenly believes it holds a truck, then the child must set aside known reality and imagine someone else as having a different intentional stance toward that reality.

Empirically testing theory-theory, modularity, and simulation accounts presents several difficulties. For example, each account acknowledges that children's performance on false belief tasks may change with age, while offering different explanations of that change—e.g., that such tasks reveal only performance, not competence limitations, or that they reflect genuine conceptual change.

The different accounts tend to generate and privilege different sorts of data as well. In particular, modular theorists early considered and generated theory-of-mind research with individuals with autism. In this line of research, the theory-of-mind hypothesis for autism proposes that the social and communicative deficits of autism reflect neurological impairment to a theory-of-mind module leading to deficits in the normally developing ability to construe persons in terms of mental states (Baron-Cohen et al., 1993). This hypothesis has proven both productive and controversial—sparking considerable research on the understanding that people with autism have mental states and sparking alternative proposals as to the central impairments of autism. For example, several studies show impairment in reasoning about mental states in high-functioning people with autism who, at the same time, show very good reasoning about physical phenomena (e.g., Baron-Cohen, 1995). A precise comparison has targeted the understanding that people with autism have false beliefs versus false photographs. Parallel tasks requiring recognition of a false mental representation—an individual's outdated and hence false belief—versus recognition of a false physical representation—an outdated and hence incorrect photograph—yield similar results for normal 4-year-olds but very different results for children with autism (Leekam & Perner, 1991; Leslie & Thaiss, 1992). High-functioning individuals with autism show very good performance on false photos, yet poor performance on false beliefs. Thus, their false belief errors are not due to an inability to reason logically or to follow the target tasks, but instead strongly imply a specific deficit in mental state understanding. These sorts of deficits in psychological reasoning are not apparent in control groups of subjects with Downs Syndrome, general retardation, or specific language delays (Baron-Cohen, 1995).

At the least, these data provide further support for domain-specific differences in reasoning about persons versus physical objects. In addition, they provide initial support for the notion of a theory of mind mental module. One implication of positing a theory of mind module, however, is that individuals who are *not* impaired in that module—that is, do not have autism—should achieve landmark mental state understandings on a roughly standard maturational timetable. In contrast, if expertise or theory-theory accounts more adequately capture these developing abilities, individuals who are exposed to very different amounts of mental state data should acquire mental state understandings on different timetables. In this regard, consider deaf individuals raised by hearing parents. Many hearing parents cannot sign, and even hearing parents who learn signing in order to communicate with their deaf children are generally poor signers, typically using short phrases about here-and-now referents and avoiding talk about complex, unobservable phenomena such as mental states (Marschak, 1993; Peterson & Siegal, 1995). Thus, most deaf children of hearing parents have relatively little access to mental state conversation until they join a community of fluent signers (often not until primary school). Two recent studies of such deaf preschool children's performance on theory-of-mind tasks show delays and deficiencies comparable to those of children with autism (Gale et al., 1996; Peterson & Siegal, 1995). These preliminary data thus challenge neurological maturational accounts such as the modular ones of Baron-Cohen and Leslie.

Data from 2-year-olds also help contrast different explanatory accounts. Consider young children's use of mental-psychological language. Children begin referring to people's emotions, desires, perceptions, and even thoughts and knowledge at an early age via such words as *happy, sad, want, think,* and *know* (Bretherton & Beeghley, 1982; Furrow et al., 1992; Ridgeway et al., 1985). Moreover, children use these terms to refer to people's internal mental states distinct from their external behaviors, physical features, and facial expressions (Shatz et al., 1983; Wellman et al., 1995). In everyday discourse, young children refer to the mental states of self and others (Bartsch & Wellman, 1995; Dunn, Brown, Slomkowski, Tesla, & Youngblade, 1991; but see Smiley & Huttenlocher, 1989), and while they refer to desires and emotions by 2 years or younger, they do not refer to thoughts and beliefs until about 3 years (Bartsch & Wellman, 1995; Brown & Dunn, 1991). Such very young children refer to desires and emotions, but not beliefs and thoughts, even though parents talk to them about beliefs and thoughts, as well as desires and emotions (Bartsch & Wellman, 1995).

These data pose challenges to an innatist account such as Fodor's. If children are born knowing about both beliefs and desires, if they eagerly communicate about mental states generally, why talk about desires but not beliefs? The data also provide some evidence relevant to theory theory versus simulation accounts. On Harris's simulation account, for example, talk about one's own desires and one's own beliefs should develop before talk about others' desires and beliefs. Talk about false beliefs, however, should be notably later because here reality is known and needs to be overridden as well. On a theory-theory account, however, talk about desires should include attributions to self and other—desires are generic constructs used to explain states or acts of both self and other—and talk about desires should precede talk about beliefs because these two are quite different theoretical constructs. The data from everyday conversations conform closely to theory-theory expectations: children talk about desires for self and others early on; they fail to talk about beliefs, even their own beliefs or theoretically easy-to-simulate beliefs, and when talk about beliefs first appears, it includes reference to false beliefs as well as beliefs of self and others (Bartsch & Wellman, 1995).

Infants

Even quite young infants demonstrate certain distinctive social behaviors. They cry, smile, and begin to become emotionally attached to others; they preferentially attend to faces—or, at first, the sorts of complex, detailed, high-contrast stimuli that faces represent (Banks & Salapatek, 1983; Johnson & Morton, 1991; Nelson, 1987); they imitate certain human actions, especially facial movements (Meltzoff & Moore, 1983). In short, infants attend to people as a special sort of object. Consequently, in infancy, children appear to develop certain expectations about persons that contrast with their expectations about physical objects. Within the first year of life, infants will imitate the actions of persons (Meltzoff & Moore, 1983), but not similar activities of mechanical objects (e.g., Legerstee, 1991), and they are upset in still-face research when people do not behave actively and expressively (see review by Muir & Haines, 1993). From about 3 months on, infants discriminate animate-biological motions versus random or artificial ones (e.g., Bertenthal, 1993), and toward the middle of the first year, may distinguish persons as self-propelled movers in contrast to physical objects that must be launched by external forces. For example, at 7 months (and perhaps earlier), infants appear surprised if objects begin moving without some external force causing them to do so as described in our section on naive physics, but not if people do so (Spelke, Phillips, & Woodward, 1995). At 10 months (and perhaps earlier), infants easily learn to push a lever in order to set an inanimate object (a picture) in motion but are unable to learn to push the lever in order to make a person wave and smile (Golinkoff et al., 1984).

Understanding that certain objects move on their own whereas others do not helps infants separate animate from inanimate things and helps infants recognize "that they are like other human beings as opposed to inanimate stimuli" (Legerstee, 1992, p. 65). But conceiving of persons as animate in the sense of self-moving requires no distinctive psychological conception of them: fleas are animate entities and cars are self moving, but neither requires a theory of mind to be understood. A psychological conception of persons and states requires more than a conception of self-propulsion or animacy. A common claim is that it requires something like an understanding of intentionality, as philosophers use that term (Baldwin & Moses, 1994; Brentano, 1874; Dennett, 1987; Perner, 1991; Wellman, 1993). Both beliefs and desires are intentional states in that they are internal experiences about or toward some object—a belief about an apple. Note that, in this sort of analysis, an ordinary intentional act—deliberately reaching for an apple—manifests intentionality in two related senses. In the narrower everyday sense, it is intentional because it is purposeful. In the broader philosophical sense, it reflects an intentional state, such as a goal (to get the apple), a desire (for the apple), or a belief (that's an apple). Intentional acts and states in this sense are very different from merely self-propelled motion.

Researchers describe a transition in social interaction, evident in the period from 8 to 14 months, in which the infant comes to see self and others in notably different terms. Infants at this age are said to show a sense of subjectivity (Stern, 1985), secondary intersubjectivity (Trevarthen & Hubley, 1978), intentional communication (Bates et al., 1979), triadic awareness (Adamson & Bakeman, 1985), or even an implicit theory of mind (Bretherton et al., 1981). The common claim here, we believe, is that infants come to view persons in intentional terms. These descriptions rest on findings that older infants (10 to 14 months or so) show emerging understanding of others' visual gaze (Butterworth, 1991; Scaife & Bruner, 1975) and pointing gestures to nearby objects (Murphy & Messer, 1977), they begin to comprehend words and engage in simple communicative interchanges with words and gestures (Bates et al., 1979), and they engage in social referencing (Feinman, 1982; Sorce et al., 1985). These descriptions of the development of intentional understanding at around 12 months are intriguing, insightful, and may eventually prove correct. At present, however, it is unclear whether behaviors that begin to appear at the end of the first year do or do not demonstrate an intentional understanding of persons, as we illustrate with three examples: infants' interpretation of gaze, social referencing, and word learning.

Older infants achieve considerable skill at following others' direction of gaze, thereby focusing on the other person's object of attention (e.g., Butterworth, 1991), and often achieving joint reference (e.g., Adamson & Bakeman, 1985). From roughly 12 to 18 months, infants achieve the ability to locate objects looked at by others even if those objects are behind the infant (outside his/her immediate visual space), if two or more targets lie in the same general direction (e.g., Butterworth & Grover, 1988; Butterworth & Jarrett, 1991). Butterworth argues, however, that at these ages, infants solve these problems geometrically, following lines of sight and probably using the nose as an important cue. If solving these problems geometrically, the infant need not construe the looker as actually seeing the object—as having perceptual experiences about the target referent. Infants, even at ages 14 to 18 months, might simply be monitoring others' gaze as a reliable cue for producing an interesting perceptual experience.

The classic social referencing phenomenon is that in certain situations, infants as young as 10 months glance to the parent and then subsequently behave toward the object or situation in accord with the affect shown by the parent. For example, when a baby is placed across a visual cliff from its mother, if the mother smiles, the baby is likely to cross, but if she appears fearful, the baby is likely to stay where she is (Sorce et al., 1985). These results are not simply due to mood contagion (e.g., seeing a negative expression causes the infant to become fearful or anxious), because infants' social referencing reactions are object specific (Hornick et al., 1987; Walden & Ogan, 1988). A rich interpretation of these demonstrations is that infants seek emotional information from parents and interpret emotional displays as providing evidence as to the parent's internal feeling about the object or situation. However, even establishing that infants' reactions are object specific does not establish that infants understand that parents' emotions are *about* objects. In Hornick et al.'s study, for example, the infants themselves were already focused on the target object (because of its novelty and salience in the experimental situation) at the time the mothers expressed their affect facially and verbally. In this situation children did not necessarily need to read the parental emotion as being about an object. Infants might simply associate parental affect to the object with which they (the infants) were presently engaged.

Even children's early comprehension of words is not clear evidence of intentional understanding of communication (Baldwin, 1991). When parents name objects for infants, their labels help pick out objects, but infant word learning could take place in either of two ways. Associatively, infants might pair adults' labels with the objects of their own (the infant's) attention. Or, intentionally, infants could understand that speakers use words to pick out specific objects and thus attempt to pair labels with the object of the speaker's intent or attention. In several studies, Baldwin has compared infants in two word-learning conditions: follow-in labeling and discrepant labeling (Baldwin, 1991, 1993). In each condition, infants were shown two novel objects. In follow-in labeling, the speaker waited until the infant first looked at one toy and then the speaker also looked at and labeled that toy. In discrepant labeling, the speaker waited for the infant to focus on one toy and then looked at and labeled the other toy. Later, infants' word learning was assessed; infants were again shown the two toys and asked comprehension questions (essentially, "Which is the [new label]?"). Baldwin found that 14-month-old infants fail to learn in either situation, 16-month- and 18-month-old infants learn in follow-in conditions, but only 18-month-olds learn correctly in the discrepant conditions. These older infants noted the attentional discrepancy, checked the speaker's attentional focus, and understood the new label as concerning the speaker's object of attention. We believe that Baldwin's data thus show intentional understanding of speakers' communicative intents by about 18 months, but not necessarily earlier. Other recent research also suggests that 18-month-olds understand human acts in intentional, goal-directed terms (e.g., Repacholi & Gopnik, 1997). For example, Meltzoff (1995) demonstrated that when imitating human actions, such as an adult who tried, but failed at some act, 18-month-olds inferred the intention and thus re-enacted successful, completed acts. This behavior was appropriately distinguished from that of children who saw the full target act, appropriate other comparison acts, or who saw an inanimate object execute the same movements that the person had.

The importance, yet ambiguity, of naive psychological understandings in infants younger than 18 months, however, has created fertile ground for competing accounts of infants' psychological understanding—modular, theory-theory, and expertise accounts. We believe that data testing these alternative accounts of infant development are as yet unavailable. Nonetheless, it is useful to contrast them briefly.

Modular accounts that propose some single theory of mind module available early in life, such as Fodor's, have trouble accommodating data that reveal developmental changes in infants' or young children's conceptions. But more generally, mental modules are part of a larger view of the mind as having a componential architecture, that is, as being composed of specialized subsystems. Theory of mind capacities themselves need not be subserved by a single module; that system might be composed of separate subsystems or modules. A series of modules triggered or maturing at separate points in development could then underlie the developmental data.

Leslie (1987) initially offered an analysis of the special sort of cognitive representations needed by a computational device in order to understand mental states—representations not just of objects or states of the world, but representations of representational states themselves, that is, metarepresentations (or lately, m-representations). He argued that mental state understanding depends on a specialized module for representing these m-representations—ToMM, or the theory-of-mind mechanism. More recently, both Leslie (1994) and Baron-Cohen (1995) have proposed a developmental sequence of mental modules culminating in ToMM. To illustrate, we consider Baron-Cohen's proposal.

According to Baron-Cohen, infants start with two modules—an Eye-Direction Detector (EDD) and an Intentionality Detector (ID)—which are followed at about 10 to 12 months of age by a Shared Attention Mechanism (SAM), and then ToMM still later. Based on research with human infants and with non-human primates, Baron-Cohen argues that attending to others' eyes is evolutionarily and developmentally important, and that an early developing module (EDD) takes in information about eyes and represents others as looking at objects in the intentional sense. Beyond representing the other as directed toward particular objects, eventually infants need to represent self and other as directed simultaneously toward the same objects. Such a shared attention representation underlies older infants' understandings of gesture and gaze according to Baron-Cohen, hence the need for SAM. Still later ToMM comes on line, which can then yield representations of persons in terms of a variety of deeper psychological-mentalistic construals—desiring, knowing, and believing things.

In arguing for the plausibility of this modular account, Baron-Cohen marshalls both developmental and clinical-neurological data. Developmentally, behaviors demonstrating shared attention (e.g., social referencing) appear late in the first year, after earlier attention to faces and eyes. Such shared attention capacities in turn precede the later onset of pretense, mental state language, and success on various theory of mind tasks. Baron-Cohen argues that there are probably two subgroups of autism: an early onset group—resulting from an impairment of SAM (Mundy & Sigman, 1989)—and a later onset group of individuals who show normal development until about 18 to 24 months (Volkmar & Klin, 1993)—resulting from an impairment to ToMM alone. Both rich and intriguing, this account is still very promissory: No evidence exists that attention to eyes in early infancy yields a representation in terms of intentional states, and the best interpretation of data from children with autism is still in dispute (see the chapters in Baron-Cohen et al., 1993), leaving ample room for alternative accounts.

Moore (Barresi & Moore, 1996; Moore, 1996; Moore & Corkum, 1994), for example, advances an expertise account—claiming that general learning mechanisms produce infants' psychological understandings and their development. Moore stresses that infants must come to understand persons in intentional terms, and stresses that this understanding must be applicable to others as well as the self. That is, in some way, the child must overcome the problem of other minds (see also Hobson, 1993; Smiley & Huttenlocher, 1989). Developmentally, according to Moore, the child arrives at a representation of psychological relations that fuses a first person and a third person perspective. The infant must come to understand the other's behavior from the inside and understand his own internal experiences from the outside, so as to see both self and other as similar, psychologically related objects.

In Moore's account, infants slowly learn a variety of interpersonal behaviors and routines over the first year of life because of certain attentional dispositions—such as preference for faces—and certain general learning mechanisms—such as imitation and contingency learning. One outcome of these factors is that by the end of the first year, the infant increasingly shares attention with others, that is, the infant and adult attend to and behave similarly with the same objects. Importantly, at this point, the infant does not yet appreciate that both persons are psychologically relating to (looking at, thinking about) objects. Nonetheless, the infant tends to be engaged with adult partners in such special matching situations. Similarly, adults' tendency to imitate infants means that adults are often behaviorally providing visual displays coincidentally matched to infants' inner experiences. These situations provide the infant with matched first person and third person information about the same person-object relation. In these special situations, according to Moore and colleagues, the infant first achieves a rudimentary representation of intentional relations, a representation that literally fuses first and third person views and is not attributable independently to either self or other. Only at the end of infancy, late in the second year, based on experience in such matched situations and on increasing module; that system might be composed of separate subsystems or modules. A series of modules triggered or maturing at separate points in development could then underlie the developmental data.

Leslie (1987) initially offered an analysis of the special sort of cognitive representations needed by a computational device in order to understand mental states—representations not just of objects or states of the world, but representations of representational states themselves, that is, metarepresentations (or lately, m-representations). He argued that mental state understanding depends on a specialized module for representing these m-representations—ToMM, or the theory-of-mind mechanism. More recently, both Leslie (1994) and Baron-Cohen (1995) have proposed a developmental sequence of mental modules culminating in ToMM. To illustrate, we consider Baron-Cohen's proposal.

According to Baron-Cohen, infants start with two modules—an Eye-Direction Detector (EDD) and an Intentionality Detector (ID)—which are followed at about 10 to 12 months of age by a Shared Attention Mechanism (SAM), and then ToMM still later. Based on research with human infants and with non-human primates, Baron-Cohen argues that attending to others' eyes is evolutionarily and developmentally important, and that an early developing module (EDD) takes in information about eyes and represents others as looking at objects in the intentional sense. Beyond representing the other as directed toward particular objects, eventually infants need to represent self and other as directed simultaneously toward the same objects. Such a shared attention representation underlies older infants' understandings of gesture and gaze according to Baron-Cohen, hence the need for SAM. Still later ToMM comes on line, which can then yield representations of persons in terms of a variety of deeper psychological-mentalistic construals—desiring, knowing, and believing things.

In arguing for the plausibility of this modular account, Baron-Cohen marshalls both developmental and clinical-neurological data. Developmentally, behaviors demonstrating shared attention (e.g., social referencing) appear late in the first year, after earlier attention to faces and eyes. Such shared attention capacities in turn precede the later onset of pretense, mental state language, and success on various theory of mind tasks. Baron-Cohen argues that there are probably two subgroups of autism: an early onset group—resulting from an impairment of SAM (Mundy & Sigman, 1989)—and a later onset group of individuals who show normal development until about 18 to 24 months (Volkmar & Klin, 1993)—resulting from an impairment to ToMM alone. Both rich and intriguing, this account is still very promissory: No evidence exists that attention to eyes in early infancy yields a representation in terms of intentional states, and the best interpretation of data from children with autism is still in dispute (see the chapters in Baron-Cohen et al., 1993), leaving ample room for alternative accounts.

Moore (Barresi & Moore, 1996; Moore, 1996; Moore & Corkum, 1994), for example, advances an expertise account—claiming that general learning mechanisms produce infants' psychological understandings and their development. Moore stresses that infants must come to understand persons in intentional terms, and stresses that this understanding must be applicable to others as well as the self. That is, in some way, the child must overcome the problem of other minds (see also Hobson, 1993; Smiley & Huttenlocher, 1989). Developmentally, according to Moore, the child arrives at a representation of psychological relations that fuses a first person and a third person perspective. The infant must come to understand the other's behavior from the inside and understand his own internal experiences from the outside, so as to see both self and other as similar, psychologically related objects.

In Moore's account, infants slowly learn a variety of interpersonal behaviors and routines over the first year of life because of certain attentional dispositions—such as preference for faces—and certain general learning mechanisms—such as imitation and contingency learning. One outcome of these factors is that by the end of the first year, the infant increasingly shares attention with others, that is, the infant and adult attend to and behave similarly with the same objects. Importantly, at this point, the infant does not yet appreciate that both persons are psychologically relating to (looking at, thinking about) objects. Nonetheless, the infant tends to be engaged with adult partners in such special matching situations. Similarly, adults' tendency to imitate infants means that adults are often behaviorally providing visual displays coincidentally matched to infants' inner experiences. These situations provide the infant with matched first person and third person information about the same person-object relation. In these special situations, according to Moore and colleagues, the infant first achieves a rudimentary representation of intentional relations, a representation that literally fuses first and third person views and is not attributable independently to either self or other. Only at the end of infancy, late in the second year, based on experience in such matched situations and on increasing cognitive ability to hold multiple sources of information in mind in a common representation, does the infant become able to represent a generic psychological relation attributable to either self or other.

Gopnik and Meltzoff (1997) provide a detailed theory-theory account of developments from infancy on. They argue that infants begin life with an initial theory of action, but then accumulate transitional auxiliary hypotheses leading to several intermediate theories that result in a first theory of mind. The infant's first theory of mind is nonrepresentational and so must develop further into a representational theory of mind. Like Moore, Gopnik and Meltzoff assume that it is crucial for the infant to be able to represent self and other similarly in a common format. However, they assume that such a representation is the starting state for infant understanding of persons rather than the culmination of two years of developing expertise and experience. For Gopnik and Meltzoff, evidence for this claim comes from demonstrations of infants', even neonates' (Meltzoff & Moore, 1983), imitation of facial gestures. Since the infant cannot see his or her own face, imitating facial gestures requires mapping visual perceptions of others' movements along with internally felt experiences of self's unseen movements in the same representation.

This initial "like me" representation is strictly tied to bodily movements and is the basis for an initial understanding of bodily movement, an initial theory of action. Importantly, the initial theory provides the starting state for several expansions to the infant's understanding. Specifically, Gopnik and Meltzoff (1997) spell out a series of transitional states leading from early infancy to the 9-month-old theory. This later theory includes a distinction between persons and objects, and between the sorts of physical actions needed to act on objects versus the different sorts of actions needed to interact with persons. Experience, including various forms of imitation, provides the data that transform the intial theory into the later one. By the end of the first year, the infant achieves an understanding of persons as special psychological actors acting on a world of objects and interacting with other people.

Conclusions

Whether modular, expertise, or theory-theory accounts of crucial developments during infancy turn out to be most useful, the clear fact remains that children by preschool age in a variety of countries—North America, England, Europe, Australia, Turkey, Japan, and the Cameroons—construe people in terms of mental states that determine how they act and interact. This naive psychological understanding contrasts quite clearly with an understanding of physical objects and forces. Even young children believe that contents and states of mind are mental, subjective, and immaterial, whereas contents and states of the physical world are substantial, objective, and material. This distinction is evident in basic form in toddlers, arguably based on a still earlier distinction in infants between inanimate object properties and motions and animate self-propelled entities and motions. One question we address in the next section is: Do young children understand that people and animals are also biological creatures, and thus, do they distinguish a domain of biological phenomena from psychological ones?

NAIVE BIOLOGY

Biological understandings concern the distinction between living and nonliving things, the relation of humans to other species, and natural processes such as illness, digestion, and birth. At minimum, thinking biologically requires the realization that certain entities operate outside the forces of mechanical or belief-desire causation. Moreover, thinking biologically requires an understanding of specifically biological causal forces such as growth, reproduction, and inheritance. Biological conceptions have recently received considerable attention for at least two reasons. Like physics and psychology, biological understandings are important and far-reaching, encompassing the living world at large, ourselves, plants, and other animals. Moreover, biological phenomena are linked to issues of categorization. Plants and animals are richly-structured, inference-promoting entities (Gelman & Markman, 1986; Keil, 1989) and are universally organized into hierarchically structured taxonomic systems (Atran, 1990; Berlin, 1992; Malt, 1995). Although biological categories may or may not be privileged in this respect (as discussed later), classification systems of biological kinds provide a paradigm case for considering issues of categorization.

As in the previous sections, our discussion focuses on two issues of central importance: When in development is there a separate biological domain, and how can that domain best be characterized? Most of the relevant evidence comes from studies of children preschool age and older, though we also refer to research with infants.

When Is There a Separate Biological Domain?

Biology constitutes a domain separate from physics or psychology for adults in our culture. Adults recognize a variety of specifically biological processes (e.g., inheritance, photosynthesis). They attribute being alive to a set of entities that share few outwardly perceivable similarities, but many important structures and functions (animals and plants are alive, but not dolls or fake plants). They report that all and only living things can reproduce, or need to eat or breathe, and recognize the existence of biological processes even in atypical organisms (e.g., germs). Furthermore, adults treat the living-nonliving distinction as ontological, for example, reporting that it is not simply false but rather makes no sense to say things such as "the chair is alive."

It is clear that at least the more sophisticated versions of these beliefs develop. Newborns do not conceive of germs, and 3-year-olds do not understand how the circulatory system works. At what point can children be said to distinguish a separate domain of biology? There are at least two plausible ways in which young children may fail to do so. First, biology could be confused in children's minds with psychology—children may think that all animate phenomena are governed by an organism's motivations, feelings, or beliefs, or social forces such as convention and morality (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, failing to give special weight to specifically biological features (Gelman & Coley, 1991; Keil, 1989).

Biological Entities

As noted earlier, even infants readily distinguish animals (especially people) from inanimate objects. For example, older infants distinguish animals from vehicles based on properties such as the capacity to drink or sleep (Mandler & McDonough, in press). However, grasping a distinction between animate and inanimate things, albeit basic to a mature grasp of biology, is insufficient evidence for a specifically biological understanding. To provide evidence for a biological distinction, it is crucial to ask children about items that unconfound animacy and life—items such as plants, which are living but inanimate, or robots, which are animate-like but not alive. In fact, when asked if plants are alive, elementary school children often say "no" (Carey, 1985; Hatano et al., 1993; Richards & Siegler, 1986). However, there are two different interpretations consistent with this error. On the one hand, children may use psychological criteria (e.g., desires and goals) rather than biological criteria to respond, categorizing plants as non-living because plants cannot think, want, or plan. This would imply failure to appreciate a biological domain. On the other hand, perhaps young children recognize a distinct biological domain, but one that excludes plants. According to this view, children could recognize the appropriate ontological domain (biology), but err in its scope of application (i.e., determining precisely which things are biological). This second account would also imply that under certain circumstances, young children might readily learn to treat plants as biological entities.

In support of the second account, more recent studies suggest that 3- and 4-year-olds distinguish living things (including plants) from human artifacts in several respects. These studies differ from past work in precisely focusing children on specific biological properties rather than generally asking them to classify items as alive or not alive. Thus, preschool children recognize that plants, like animals, can grow (Hickling & Gelman, 1995; Inagaki & Hatano, 1996), heal without human intervention (Backscheider, Shatz, & Gelman, 1993), or decompose and become noxious (Springer, Ngyuen, & Samaniego, 1996). Preschoolers may also distinguish biological from nonbiological natural things in terms of whether their parts or properties have a predetermined function or purpose (also known as a teleological construal). For example, the green color of a plant helps it to acquire energy, whereas the green color of an emerald has no function for that emerald (Keil, 1992, 1994). There is currently debate as to whether children's teleological explanations (e.g., "the heart works because it wants to move the blood around the body") stem from a distinctive vitalistic biology (Inagaki & Hatano, 1993) or a psychological understanding of biological phenomena (Carey, 1995).

Biological Causal Mechanisms

Recent studies demonstrate that preschool children view at least some biological processes as *outside* the domains of psychology or physics. For example, 4- and 5-year-olds judge that processes such as breathing, getting tired or sleepy, and gaining weight cannot be controlled or modified by merely psychological interventions (Inagaki & Hatano, 1993; Schult & Wellman, in press). Similarly, they say that people cannot prevent an animal from growing (Inagaki & Hatano, 1987). At the same time, young children hold many misconceptions regarding certain biological processes, particularly internal bodily processes that involve specialized structures, such as respiration, digestion, or circulation of the blood (Carey, 1985).

Demonstrating that children understand that some phenomena fall outside of the scope of psychological and mechanical forces does not necessarily demonstrate a specifically biological causal understanding. What might be distinctive biological processes and mechanisms (in the way that mechanical-dynamic collisions are distinctively physical, say) that children could plausibly grasp early in life? We suspect, as have other researchers, that likely candidates include the processes of biological movement, growth, inheritance, and illness. There may be a basic level of phenomena that children focus on in their early conceptualizations—topics that are neither too broad (such as evolution), nor too narrow (such as cellular mitosis). Movement, growth, inheritance, and illness are notable in this regard because they involve the entire visible animal or plant, rather than the workings of parts (e.g., lungs, heart) or obscure processes (e.g., digestion). Perhaps more importantly, movement, growth, inheritance, and illness/injury have broad implications for interpreting an animal's behavior and judging its identity. For example, adults rely on movement to make decisions regarding agency; they rely on growth to track identity of an animal over time; and they use biological inheritance when predicting or explaining the characteristics of offspring. Furthermore, parents may be more likely to talk about movement, growth, kinship, and illness than internal bodily processes.

It is plausible to suspect that children's earliest understandings of biological processes concern movement, given the primacy of movement in infancy (e.g., Bertenthal et al., 1985). Moreover, children's causal explanations differ for animal versus artifact movement (Gelman, Durgin, & Kaufman, 1995; Massey & Gelman, 1988). Children aged 3 and 4 years realize that animals, but not simple artifacts, move as the result of self-generated powers (R. Gelman, 1990; S. Gelman & Gottfried, 1996). Children as young as 3 years of age honor domain differences even with item movements that appear to be self-generated (e.g., a hopping chinchilla is said to move by itself; a toy that seemingly propels itself across a table is said to move not by itself but rather as a result of human intervention).

Children also understand several aspects of growth by preschool age. They understand that growth and development are constrained: animals get bigger with age, not smaller; animals can take on a more complex form (e.g., caterpillar to butterfly), but not a simpler form (e.g., butterfly to caterpillar; Rosengren, Gelman, Kalish, & McCormick, 1991). Only animals and plants undergo the distinctive process of growth; human artifacts such as toys or machines cannot (Carey, 1985; Rosengren et al., 1991). Similarly, Backscheider et al. (1993) found that 3- and 4-year-old children report that living things are capable of self-healing; artifacts are not. For example, if the fur is removed from a dog, children report that it can grow back by itself. But if the hair is cut off a doll, children report that it requires human intervention to be restored.

Preschool children appear to understand the constraints on growth much earlier than they understand the constraints on nonbiological processes of change involving animals. With nonbiological processes such as surgical operations, children below age 7 accept as wide a range of transformations as possible, including those adults deem impossible (e.g., a cat becoming a dog; DeVries, 1969; Keil, 1989). But for natural transformations, children realize that the changes that can occur are bounded and that identity remains constant across those changes (Gelman, 1993; Rosengren et al., 1994). In this way, young children give evidence that they are sensitive to whether the mechanism inducing change is a natural, biological one or an artificial one.

Inheritance is a specifically biological process; all and only living things have offspring to which they are capable of passing along inherited characteristics. Although learning the details of the process certainly requires instruction, young children have an early grasp of some of the basic aspects. Springer (1992; Springer & Keil, 1989) asked preschool children to predict which features of parents would be inherited by their offspring. For example, they were told that "Mr. and Mrs. Bull . . . were both born with pink hearts inside their chests instead of normal-colored hearts," and were asked to predict whether their children would be born with a normal-colored heart or a pink heart. Subjects more often treated a feature as inherited when it led to biological outcomes (e.g., the capacity to eat more) than when it led to psychological outcomes (e.g., anger), thus suggesting that preschool children believe that the process of inheritance operates over specifically biological properties. Preschool children also have reasonable expectations about the means by which biological properties are transmitted from parent to offspring, for example, appealing to internal causal mechanisms rather than psychological or artificialistic explanations to explain why a biological entity is a certain color (Springer & Keil, 1991). Importantly, Springer

(1992) found that preschool children are aware of the biological implications of kinship. They expect animals of the same family to share physical features (e.g., tiny bones inside), even in the strong case when perceptual similarity is placed in conflict with kinship.

Related to the notion of inheritance is the understanding that individuals have a certain innate potential that is determined at or before birth and emerges in a broad array of environmental contexts. For example, a mouse may be genetically programmed to have black-and-white fur, even though it is hairless at birth. By age 4 years, children appreciate that animals have innate potential of this sort, and they quickly apply this understanding to plant seeds as well. When children are told about infant animals and seeds that are raised in an environment more suited to another species (e.g., a calf raised among pigs; a seed that came from an apple and was planted in a pot full of flowers), they report that the animals and plants will have species-appropriate characteristics (e.g., the adult cow will moo and have a straight tail; Gelman & Wellman, 1991). Children believe that this sort of innate potential exists for humans as well as other animals. Taylor (1993) found that young children expect that gender-linked characteristics (e.g., play preferences and aptitudes) are innately determined and unaffected by environmental opportunities. Children do not start to acknowledge the importance of environmental influence until middle childhood (roughly age 9 or 10 years; Taylor, 1993).

These data are consistent with the interpretation that children expect each category member to possess an underlying essential nature that persists even in the absence of a normal environment. It is possible, however, that children make these judgments without having a specifically biological understanding. Carey (1995) rightly warns of the danger of overattributing understandings to children based on similarities between children's and adults' knowledge. Specifically, Solomon et al. (1996) argue that in Gelman and Wellman's study, children could still apply a psychological rather than biological construal. Solomon et al. conducted a set of studies that highlighted the nurturing, family-like aspects of the adoptive family, and tested both biological and psychological properties. Using this task, it was not until 7 years of age that children relied on biological parents for drawing inferences about the adopted child. Similarly, children did not distinguish biological from psychological properties until age 7. However, Solomon et al.'s task was considerably more complex than that of Gelman and Wellman, and other evidence suggests that preschool children do grasp that crucial properties are determined by the birth parents, when the experimental task is presented in a clear and simple manner (Hirschfeld, 1996; Springer, 1995). We suggest, therefore, that preschoolers grasp the general principle that birth parents are more predictive of certain properties than are adoptive parents, but that children still must sort out which particular properties are heritable (the latter being an issue that scientists continue to debate).

In sum, we believe that children show an early grasp of biological processes, at least when focusing primarily on animals and on aspects that (a) involve the whole organism at a basic level of consideration, (b) have implications for important, everyday behaviors and identities, and (c) are likely to be topics of discussion with others. Data regarding early understanding of movement, growth, and inheritance suggest—with some controversy—a generally sensible grasp of several biological processes in preschool-age children.

Unobservables

Unobservable constructs can lead to classifications in which category instances differ from one another in salient ways, yet share underlying properties relevant to the domain. For example, adults generally classify plants and animals together into a category of living things, largely because of beliefs regarding their biological commonalities (e.g., both plants and animals grow, reproduce, take in nutrients, and can heal themselves). Without such knowledge, there may be no reason for grouping plants and animals together; as noted earlier, young children often fail to treat them as a single category of living things.

How might children demonstrate an appreciation of unobservables in the biological realm? Consider contamination and illness, both of which can (for adults) make reference to germs. On the one hand, children might have considerable difficulty understanding contamination and illness, because both phenomena would seem to arise out of nowhere—for example, a person may go to bed feeling fine but wake up in the morning with a nasty rash and high fever. The causal underpinnings of particular cases of illness and contamination are not visible, the effects or visible symptoms are often delayed (by hours, days, even weeks or years), and nonbiological accounts are plausible (e.g., immanent justice, wrath of God, bad luck).

On the other hand, the very fact that contamination and illness can become evident without apparent cause may facilitate children's understanding. The existence of seemingly inexplicable, yet highly salient events may pique children's interest and lead them to search for identifiable, albeit nonapparent, causal agents (such as germs). Recent evidence suggests that preschool children appreciate that, with both illness and contamination, an entity can induce illness or be contaminated despite lack of visible evidence (Au et al., 1993; Rosen & Rozin, 1993; Siegal, 1988). For example, Kalish (1996) finds that 4- and 5-year-olds make predictions about who will get sick (in cases of contamination and contagion) based on the presence or absence of invisible germs: Children judge that Bobby will get sick if he eats an apple that falls in the garbage—unless they learn that there were no germs in the garbage.

In biology, another important example of unobservables is a category essence—an underlying nature hypothesized to determine identity and the observable qualities that category members have in common (Gelman, Coley, & Gottfried, 1994; Medin, 1989). For example, the essence of the tiger category may be a distinctive DNA profile; the essence of the water category may be H_2O (Putnam, 1973; Schwartz, 1979; but see Malt, 1994). Even without knowing precisely what it is that holds category members together, children and adults may assume that some fundamental, common feature(s) exist, thus leaving a placeholder for an essence that will eventually be discovered (Atran, 1990; Gelman & Medin, 1993). The claim that children treat categories as having essences does not imply a particular set of beliefs concerning what that essence is. It does, however, imply some general properties: that the essence resides within the organism, is fixed and relatively unmalleable, and is responsible for numerous other features including those not yet known or discovered.

Children's biological categorizations demonstrate two sorts of evidence that are consistent with essentialist reasoning: Children treat internal parts as privileged, and they regularly draw inductive inferences on the basis of category membership rather than surface appearances. Regarding internal parts, children are highly sensible if not specifically accurate about the possible internal parts of animals by 3 or 4 years of age (R. Gelman, 1990; S. Gelman & O'Reilly, 1988; Simons & Keil, 1995). Moreover, as noted earlier, children draw inferences about identity and capacity to function based on internal parts (S. Gelman & Wellman, 1991). Relatedly, children draw a rich array of inferences from one category member to another very dissimilar category member or even to the entire category. For example, S. Gelman and Markman (1986) presented preschool children with items in which category membership was put into conflict with superficial appearances, such as a brontosaurus, a rhinoceros, and a triceratops, which were labeled as *dinosaur, rhinoceros,* and *dinosaur,* respectively. Category labels and outward appearances conflicted: The brontosaurus and triceratops are members of the same category, whereas the rhinoceros and triceratops looked more alike. Then children learned a new property of the brontosaurus and the rhinoceros (that they had cold blood and warm blood, respectively), and were asked which property was true of the triceratops. The results of this and other related experiments showed that by 2½ years of age, children base inferences on category membership, despite conflicting surface appearances (S. Gelman & Coley, 1990; Shipley, 1993).

The claim that young children think of biological entities in terms of underlying essences has been called into question by the suggestion that children have a general shape bias in their interpretations of novel count nouns. According to this proposal, new words (e.g., a "dax") are assumed to refer to a set of objects that share a common shape, even objects that are taxonomically unrelated for adults (Imai, Gentner, & Uchida, 1994; Landau, Smith, & Jones, 1988). A shape bias would thus mean that underlying, essential status is irrelevant when extending words (e.g., toy bears and real bears are both bears because they have a common shape, despite the fact that children understand that toys are not real). In favor of this position, many studies indicate that shape is salient for children, particularly in word-learning contexts (Baldwin, 1992; Smith, Jones, & Landau, 1992). However, children may attend to shape not because it is the basis on which words are extended, but rather because it correlates with and thus provides good information about what kind of thing an object is (Soja, Carey, & Spelke, 1992). Indeed, children override similarity (including shape) when extending novel words at the basic level (Golinkoff, Shuff-Bailey, Olguin, & Ruan, 1995), and children make use of information other than shape, such as object function and syntax, to extend new words (Gathercole, Cramer, Somerville, & Op de Haar, 1995).

In any case, the shape-bias hypothesis seems incomplete, given that features are either highlighted or downplayed, depending on how the child conceptualizes the larger category to which the object belongs. For example, Jones, Smith, and Landau (1991) found that when 2- and 3-year-olds were asked to classify simple novel objects (e.g., geometric shapes made of wood, wire, or sponge), children attended primarily to shape, yet when the same items had plastic eyes attached, subjects attended to both shape and texture. Apparently, the addition of eyes changed the child's conception of the object's ontological status (from object to animal), which in turn influenced categorization judgments. Similarly, Ward, Becker, Hass, and Vela (1991) found that although children generally rely on shape for classifying and extending novel words, they do not do so when the shape is a temporary one (e.g., a snake curled into a circle). Moreover, Soja, Carey, and Spelke (1991) demonstrated that although children use shape when learning words for objects, they do not do so when learning words for substances.

Coherence

To what extent do young children's biological beliefs cohere into a biological system? Although the issue has rarely been examined, evidence suggests that there is some interrelatedness of children's biological knowledge by late preschool. Backscheider (1993) told 4-year-olds about items that possessed either a biological or a non-biological property, then asked children to infer the presence or absence of other biological and non-biological properties. Children were not permitted to see the item during questioning. For example, they were told for one item, "This is something that grows" and were asked whether it was held together with nails and screws, whether if it got a scratch it would get better all by itself, and so forth. When told that an item had one biological property, subjects inferred that it had other biological (but not nonbiological) properties; when told that an item had one nonbiological property, they inferred that it had other nonbiological (but not biological) properties.

Intriguingly, children's assumption that biological properties intercorrelate may at times be stronger than that of adults. Kalish (1996) found that, for preschool children, the concept of illness may be "more coherent and inferentially rich" than for adults. Specifically, whereas adults saw no strong links among illness and other features (e.g., fevers), children viewed illnesses as strongly predictive of fevers and consistently requiring medicine, and they viewed contagion as based on a single underlying cause (i.e., infection). Thus, children may search for and expect causal interconnections among biological phenomena even when they don't exist.

Finally, an issue central to addressing children's coherent biological reasoning concerns the inductive function of categories, that is, their potential to generate novel inferences. For adults, categories function to extend knowledge beyond what is obvious or already known. For example, after learning that one dog has leukocytes inside it, subjects are likely to infer that other dogs also have leukocytes inside them (Gelman & Markman, 1986). Categories that are tied to theories or larger framework understandings promote especially many inferences concerning novel features (Markman, 1989; Quine, 1977). As reviewed above, even very young children use biological categories (e.g., "dinosaur") to generate novel inferences about unfamiliar organisms.

How to Characterize the Biological Domain

In the biological domain, as in naive physics and psychology, modularity, theory-theory, and expertise approaches have offered different characterizations of the relatively rich knowledge base young children have acquired.

Modularity Position

One proposal is that children have an innate biological module. For example, Pinker (1994) proposes four "distinctive properties of living things" that humans are predisposed to notice: (a) Organisms fall into species in which members share tight clusters of similar features, (b) There is a distinctive logical (non-overlapping, hierarchical) structure that we use to classify biological species, (c) Biological organisms, being self-preserving systems, are "governed by dynamic physiological processes that are lawful even when hidden," and (d) Members of a biological kind have a hidden essence that remains unchanged across outward changes, such as growth or reproduction.

Although Pinker cites some evidence for these properties, he does not demonstrate that they are either innate or domain-specific. For example, appreciation of physiological processes could require formal schooling, or essentialism may be a more general feature of concepts, and not specifically biological.

Perhaps the most sustained argument for the notion of biology as a distinct innate module comes from Atran (1990, 1994), who studies classification systems cross-culturally. Building on Berlin's (Berlin et al., 1973) seminal work, he finds striking cross-cultural similarities in how people organize categories of plants and animals: the existence of taxonomies, the lack of overlap among categories within a given level, the number of levels in the taxonomies, the level that is most accessible and most powerful for induction (e.g., Lopez, Atran, Coley, Medin, & Smith, 1997). He also argues that each category at the basic level of a hierarchy (the species/genus level, such as rat) is assumed by language-users to capture an underlying essence. Thus, Atran claims that biological reasoning—especially taxonomic, essentialist reasoning—is separate, special, and the result of an innate module. Three components of Atran's claims are crucial here: that taxonomic and essentializing principles are innate, that they are specific to the domain of living kinds (see also Wierzbicka, 1984), and that they are atheoretical.

In contrast to Atran's claim that taxonomizing and essentializing grow out of innate biological understandings, others suggest that taxonomizing and essentializing arise from domain-general properties of language (Carey, 1995). Some researchers (e.g., Rosch, 1978; Rosch et al., 1976) claim to find parallel hierarchical classification systems in biological and nonbiological domains, at least for adults. Shipley (1993) also advances an alternative domain-general account of how categories become organized into hierarchies. And several developmental studies find no obvious domain differences in hierarchical reasoning in young children (Anglin, 1977; Blewitt, 1989; S. Gelman et al., 1989; Waxman, 1990). Similarly, there is evidence suggesting that young children may apply essentialistic reasoning more broadly than just to biological categories (e.g., applying it to substances such as gold; S. Gelman & Markman, 1986). However, because the developmental study of class inclusion hierarchies has been dominated by the Piagetian domain-general perspective, researchers have rarely examined whether domain differences exist. These issues are in need of sustained research.

Theory View

Whereas modularity theorists focus on biological categories and their organization into hierarchies, theory theorists focus on the content of beliefs: the ontological distinction between living and nonliving things, and the distinctive biological processes of growth, reproduction, and so forth. The view that children's biological knowledge inheres in early theories has at least two distinct forms: (a) Children hold a distinctly biological theory from the start (S. Gelman & Coley, 1991; Hatano & Inagaki, 1994; Keil, 1992), and (b) children have a theoretical understanding of living things, but one that at first is psychological and only gradually emerges as a separate biological domain (Carey, 1985).

Because both these positions hold that children have specifically biological theories by age 10 (or perhaps earlier), we focus on Carey's (1985) claim that children's biological theories emerge out of their psychological theories. Carey's evidence includes children's difficulty with the concepts of life and death; their socio-psychological interpretations of biological concepts such as growth, reproduction, gender; their difficulty merging animals and plants into a concept of living things; and so forth. In all of these studies, children appeared to be ignorant about biological processes—often re-interpreting them within a psychological framework.

In contrast, the studies reviewed in the previous section indicate that children do recognize a distinctively biological domain by 4 to 6 years of age. For example, studies of gender or species constancy have found dramatically improved performance in even younger children by switching the order of items to reduce pragmatic biases (Siegal & Robinson, 1987), presenting children with potential cross-ontological changes rather than within-ontological changes (e.g., a porcupine that appears to be a cactus; Keil, 1989), or presenting children with transformations in which they need reason about only one identity at a time instead of two (S. Gelman & Wellman, 1991).

Early competence is found even in children's reasoning about humans, where psychological construals might be expected to be particularly strong. For example, Schult and Wellman (in press) specifically asked 4-year-olds about human behaviors that were either psychologically or biologically caused (e.g., hanging from a tree branch, then letting go—either because of a desire to let go or because of muscle fatigue despite a desire to hang on), and subjects provided appropriately distinct explanations for these behaviors. Similarly, Inagaki and Hatano (1993) posed direct contrasts to children—for example, a child who wanted to be fat but ate very little versus a child who wanted to be thin but ate large quantities—and found that even preschoolers could accurately report the biological consequences (e.g., which character would gain weight). It appears, then, that although the psychological may at times inappropriately intrude upon the biological, children can perform quite well when directed to think about the relevant conceptual distinctions between these two domains. At the very least, distinctively biological reasoning seems evident at 4 or 5 years rather than 9 or 10.

However, this conclusion leaves open the same two alternatives mentioned earlier. On the one hand, children's understanding of biological phenomena may be distinctly biological at all prior points in development. The recent history of studies of cognitive development suggests healthy skepticism regarding claims of developmental incompetence. Furthermore, at present there is no principled reason to expect that biological understandings clearly revealed at age 5 could not also be uncovered at ages 4, 3, or even earlier. On the other hand, however, children's biology may split off from psychology (as Carey suggested), but at an earlier point than initially proposed. At this point, there is no evidence for a specifically biological theory in infants or toddlers, but this seems to be due to a lack of appropriate methods to test the hypothesis rather than the presence of evidence contradicting the view that the domains are distinct early in development.

Expertise

Modular and theory views of children's developing understanding of biological phenomena predominate in current theorizing. However, perhaps the most intuitive, common sense view of how children's biological knowledge grows is an expertise view: that children learn these things because people teach them. Certainly expertise influences knowledge acquisition in the biological domain (Chi, Hutchinson, & Robin, 1989; Inagaki, 1990; Tanaka & Taylor, 1991). For example, Springer (1995) found that learning that babies grow inside their mothers prior to birth may be a pivotal piece of knowledge leading to children's understanding of kinship as biological. A greater amount of specific knowledge about biological phenomena, typically acquired from more knowledgeable adults, plays a powerful role in children's developing biologies.

Expertise rests on acquiring increasing information about a domain and thus implies close linkages between sources of informational input and knowledge. One way to evaluate the expertise approach, therefore, is to ask how close a link can be found between sources of expertise (specifically, information in the environment available to the child) and children's knowledge. One set of issues involves timing, specifically whether there is a critical period for input, suggesting that other developmental factors—not input alone—influence rates and patterns of learning. Another set of issues concerns untaught beliefs (beliefs that emerge either without input or on the basis of only slight, indirect, or subtle input), or self-constructed errors (those that are not merely incomplete versions of the input or confusions of the input). If there are variations in learning due to timing or content, or mismatches between the input and the conceptual understanding, then factors other than expertise may be responsible.

At the very least, what is needed is a more detailed description of the kinds of input available to children concerning biological categories and processes. Moreover, this same prescription applies for the domains of physical and psychological reasoning. The few studies that exist suggest that although parents provide a richly informative database concerning category labels, taxonomic relatedness, and even some of the apparent properties that are characteristic of categories at different taxonomic levels (e.g., Callanan, 1985, 1990), their discussion of biological essences and causal processes is at best incomplete (S. Gelman, Coley, Rosengren, Hartman, & Pappas, 1995). The data suggest that parental input may provide useful information for children, yet is unlikely to be the sole or primary source of children's biological beliefs.

Furthermore, biological knowledge seems to entail untaught or self-constructed errors. We illustrate with two examples: evolutionary accounts of speciation, and understanding of the relation between humans and non-human animals. Evolutionary theory has been widely accepted in the scientific community for many years, yet nonscientists (children and adults alike) are remarkably resistant to it, either by rejecting it outright or by misinterpreting its claims (e.g., Almquist & Cronin, 1988; Engel, Clough, & Wood-Robinson, 1985). Evans (1994) suggests that this resistance to evolutionary theory arises in part because of pre-existing psychological and biological beliefs. In her own work, Evans examined beliefs about species origins ("How do you think the first X [e.g., human] got here on earth?") in children from 5 to 13 years of age. In addition to open-ended questions, children heard possible explanations that they could accept or reject, including spontaneous generationist ("it came out of the ground"), evolutionist ("it changed from a different kind of animal"), creationist ("God made it"), and artificialist ("humans made it") choices. Half the subjects were from fundamentalist Christian backgrounds, and the remainder were from non-fundamentalist backgrounds, but otherwise the groups did not differ in parent educational levels. As predicted, the older subjects in the two groups differed markedly in their explanations of species origins: Those from a fundamentalist background tended to endorse creationist accounts, whereas those from a non-fundamentalist background tended toward some form of evolutionary/adaptationist account. In contrast, the younger subjects from the two backgrounds gave remarkably similar answers, both favoring creationist accounts overall. Group differences in beliefs did not appear until middle childhood. At the earlier ages, children from distinctly different ideological backgrounds seem to have constructed remarkably similar explanations for these biological phenomena.

Relatedly, children also misconstrue the place of humans within the animal kingdom. Specifically, children appear to have great difficulty thinking of humans as one kind of animal among many—instead, they tend not to think of humans as animals at all (Carey, 1985). This tendency can be seen in Johnson, Mervis, and Boster's (1992) study of animal classifications. Children and adults were presented with triads (e.g., chimpanzee, human, dog) and asked to pair together the two instances that were the same sort of thing. Subjects—especially children—often isolated the human by grouping together the chimpanzee and the dog. Coley (1993) presented subjects with even more extreme examples (e.g., chimpanzee, human, caterpillar), and found that children again tended to isolate the human, in this case grouping together the highly dissimilar chimpanzee and caterpillar. This example again argues for powerful beliefs in childhood that do not just evidence ignorance of adult understandings, but rather conflict with them.

Conclusions

Children seem to appreciate a distinct biological domain by 4 or 5 years of age. They honor an ontological distinction between living things (including plants and animals) and non-living things; they understand something of the biological importance of self-generated movement, growth and healing, inheritance, and germs; they appeal to non-obvious biological properties; and they recognize the interrelatedness among biological properties. Below preschool age, infants and toddlers are certainly attentive to animals and animal properties (e.g., distinguishing animals from artifacts with respect to properties such as the need for water), yet there is little research with young children to demonstrate convincingly that these seemingly biological understandings are distinct from either psychological or domain-general ones.

Several theoretical positions compete to account for the developmental changes and constancies found in children's biological reasoning. There may be an innate module dedicated to the biological domain, most forcefully argued to be manifest in children's biological categories—both their internal structure (shown in an essentializing tendency) and their external structure (shown in hierarchical taxonomies). Another possibility is that children's beliefs cohere into an early-emerging (possibly innate) biological theory, in which simple heuristics such as essentialism and teleology pave the way for an increasingly sophisticated grasp of biological processes and functions. Note that, as Inagaki and Hatano remind us, it is possible that children honor a domain of biology but one that differs in fundamental ways from that of adults (scientists or lay people). A third possibility is that children may develop a biological theory itself out of a more primary psychological theory. We are skeptical of a fourth option, associated with an expertise perspective, that children develop biological knowledge primarily out of piecemeal, extensive exposure to biological information from parents, siblings, other caregivers, and the media; our skepticism reflects the powerful presuppositions children hold that endure in the face of disconfirming evidence.

CONCLUSIONS AND CHALLENGES

There are two classic questions concerning conceptual development: the descriptive question of what sorts of knowledge children have when, and the explanatory question of what sorts of mechanisms account for this knowledge. Our focus on children's ontological knowledge, understanding of unobservable entities, and causal-explanatory notions addresses the descriptive question; modular, expertise, and theory-theory accounts propose explanations for development.

Descriptions of Children's Knowledge

Within and across the three domains we have reviewed, young children reveal a core of systematic beliefs and distinctions. Even toddlers search for causes, maintain firm ontological boundaries, acknowledge unobservable entities. Most of the research on understanding of biology focuses on somewhat older children than do studies of physics and psychology, yet preschool children demonstrate insightful understanding of biological phenomena as well. These findings support a strong claim: At a young age, children distinguish at least three foundational domains of thinking. It is not yet clear how many domains children distinguish in all, nor which analytic criteria identify foundational domains of thought. Some consensus has emerged in the research, but how to identify domains remains problematic and deserves more attention.

The findings we have reviewed could conceivably be viewed as consistent with traditional characterizations of knowledge development, except for demonstrating competence at earlier ages than expected. Even this modest interpretation has broad-ranging implications, as it necessitates explaining how the knowledge is acquired so rapidly. However, we prefer a more radical interpretation, one that up-ends several assumptions about cognitive development. Specifically, it is often assumed that young children begin by attending to the perceptual, overt, surface features of phenomena and only slowly come to penetrate to more underlying, nonobvious understandings. Relatedly, children are assumed to confuse certain distinctions basic to adult thought—such as mind/body, animate/inanimate, and subjective/objective—the sorting out of which requires considerable developmental construction. Similarly, children's reasoning is often depicted as first focusing on acausal correlations between salient occurrences and only later reflecting a genuine appreciation of causal regularities and causal explanations. However, we believe that rather than being later developmental *outcomes*, concepts of causes, ontologies, and unobservables are more properly early *contributors* to knowledge development, at least in the domains of reasoning we have reviewed. If this portrait is correct, it requires a revolution in how we think about knowledge—what is most basic, what is derived, and how knowledge develops.

Causal Explanations

By preschool age at least, causal understandings are central in children's reasoning about physics, psychology, and biology. We propose that in these cases, causality is a developmental primitive, emerging early in development and influencing categorization and knowledge acquisition. In natural conversation, young children readily invoke causal reasoning, and in comparison to older persons, young children may *overattribute* causality to events. For example, randomness is quite difficult for preschoolers to comprehend; young children tend to assume that random events are causally determined (Green, 1978; Kuzmak & Gelman, 1986; Piaget, 1930). Thus, children may be causal determinists, actively expecting events to have causes (S. Gelman & Kalish, 1993).

Children's reasoning about magic further suggests that children search for causes (Harris, 1994). If children readily accepted uncaused events, they would have no need to appeal to magic. What is baffling and amusing about so-called magical events is that they have apparently either no antecedent causes or extraordinary causes. Magical events thus differ from events with merely unknown causes. Consider the rabbit-hat trick versus an electric garage-door opener. The latter is assumed to have a causal physical mechanism, so that even though the mechanism is unknown to the child, it is presumed to result somehow physically from the remote-control device. The appearance of the rabbit in the hat, in contrast, seems outside the realm of possible physical causes. It is interesting that this contrast between the magical and the merely inexplicable is available to the young child (Rosengren & Hickling, 1994).

A possible objection to this interpretation is that very young children (those below 3½, say) are notoriously poor audiences for magic. Conceivably, these very young children have yet to care about causes. Our counter-interpretation is that young children may hold so strongly to a causal view of the world that they simply don't conceive of extraordinary events and causes. This general expectation is coupled, often, with a lack of knowledge as to specific causal mechanisms: "This is another one of those events I can't yet explain; of course it has a cause—I just don't know yet what it is." Baillargeon (1994) reports that in certain cases, babies fail to be surprised by events that are impossible and should be surprising (e.g., one solid object passing through another), but that in these cases one can show that infants make auxiliary assumptions in order to resolve the apparent puzzle. In other words, even babies may at times work to avoid concluding that an event is impossible.

We assume, in fact, that in the three domains we have targeted, causal determinism works in a framework fashion: Children may be ignorant about specific causal factors but still expect that events have relevant domain-specific causes of some sort. This seems particularly likely for younger children, who are continually surrounded by inexplicable events. Why does a balloon float up to the sky instead of fall to the ground? What makes a garage door opener work? In short, an expectation that events generally have sensible causes is not the result of painstakingly observing many particular causal sequences and inferring from them the generalization that there are always causes at work. Instead, a disposition to expect causal regularity seems well in place even when children have scant knowledge of particular causes. This faith of the young child that the world is a predictable, orderly, *knowable* place enables children to proceed to understand the world in increasingly more sophisticated ways.

Ontological Knowledge

By referring to a distinction as ontological, we mean that it captures basic conceptions of what sorts of entities there are in the world. Ontological kinds are distinguishable in principle because they engender category mistakes rather than simple falsehoods (Keil, 1979; Sommers, 1963). The statement "cork is heavier than gold" is false, but the statement "ideas are heavier than gold" is neither true nor false; it is a category mistake. Ideas are not the kind of thing that can be light or heavy (except metaphorically). Similarly, the only way to understand a category mistake such as "My TV died" is by imposing a metaphorical interpretation (it broke).

Keil (1979) studied children's ontological understandings by asking children to judge category mistakes versus simple falsehoods. This method, however, requires metalinguistic judgments that are beyond the capacity of children much younger than kindergarten age. Thus, the research we have reviewed has relied on other measures. The thrust of the findings are clear: Children distinguish three very distinct kinds of entities quite early in development: bounded physical objects, mental entities, and living kinds. They judge that thoughts cannot be touched—not because thoughts are far away or behind barriers, but because they are distinctly different kinds of things from physical objects. They judge that damaged artifacts cannot heal by themselves but damaged animals can—again, not because of contextual limitations (e.g., shortage of bandages or doctors), but because only animals are capable of this. In fact, one of the more intriguing findings of the research we have reviewed is the existence of adult-like ontological distinctions at very early ages. Preschoolers, toddlers, and even babies distinguish animate from inanimate, solid object from unbounded mass, object from event, mental from physical.

The ontological distinctions demonstrated early in life are not the only ones we make as adults. That is, we are not necessarily restricted to a small, innate, or early-developing set. For example, as Carey (1991) argues, the development and emergence of new scientific theories yields the emergence of new ontologies (e.g., the distinction between heat and temperature) even for adults. What seems less clear, however, is whether the ontological distinctions we are born with can ever be erased. We suspect not—which could account in part for the enduring errors and folk beliefs that continue to undermine scientific training. For example, the (folk) ontological distinction between space and time renders the Einsteinian view of the universe (with its space-time continuum) nearly incomprehensible to most adults. Similarly, although certain folk-biological categories (e.g., tree) have no scientific counterpart, it appears that even expert botanists can't help but think in terms of them (Atran, 1990).

Children's distinctions among physical, psychological, and biological phenomena are interesting not only for how they carve up the world, but also for how children try to reason across these ontological divides. Children's attempts to understand how different domains intersect provide fruitful sources of fiction, imagination, and analogy. For example, magic typically entails human actions overriding physical laws; astrology entails physical (celestial) objects influencing the thoughts, desires, or behaviors of humans; parapsychology entails humans effecting physical consequences via mental means. These might all be considered ontological suspensions, even confusions—but of a relatively advanced sort. Ontological confusions of the less advanced sort would include a complete failure to distinguish ontological types, and (interestingly) seem not to exist even in very young children in these domains. Ontological confusions of the more advanced sort involve stretching the scope of application of one domain onto an inappropriate realm; these exist in childhood, though possibly only after the stable domain distinctions are worked out to begin with. That is, this second-level ontological confusion may represent a conceptual advance over an initially clean set of ontological distinctions. Support for this notion is the finding that magical explanations appear only at about 4 or 5 years of age (not 3)—after the infrastructure of the core domains is already in place.

Unobservables

In the domains we have reviewed, in their search for understanding and explanations, children do not simply explain overt events in terms of overt factors; they appeal instead to unobservable constructs and forces. Unobservables sometimes refer to literally invisible entities: essences, nonvisible particles, mental states. More broadly, children distinguish between at least two levels of analysis: evidential phenomena themselves (such as a parent's offspring or a person's behavior) versus explanatory, abstract concepts used to account for the evidence (such as innate potentials or beliefs). For example, consider the goal of attempting to explain why a person jumps into a swimming pool while clothed (Murphy & Medin, 1985). One could describe the covariation of related factors, all at the same behavioral level (e.g., whether others are doing the same thing, or whether the target person tends to do this on other days). In contrast, one could explain the behavior in terms of a mechanism that is phrased at a different level of analysis (e.g., the person's physiological state—inebriated—or psychological state—giddy). Adults and even young children appeal to the latter sort of explanation (Ahn et al., 1995; White, 1995).

One implication of this early appeal to unobservables is that, as Simons and Keil (1995) recently argued, children's reasoning may in places proceed not from concrete to abstract, as is commonly assumed, but rather from abstract to concrete (or global to specific; Mandler et al., 1991). Indeed, in the domains we have reviewed, our argument is precisely of this sort. Children understand and appeal to certain framework notions in a very general way, prior to knowledge of the concrete details. Importantly, however, in other areas the concrete-to-abstract view is probably correct; for certain phenomena, children undoubtedly build more abstract understandings off a database of particulars. Thus, an interesting question becomes *when* development shifts from abstract to concrete, and *when* the reverse. We suggest that the abstract-to-concrete direction of change will be found for domains in which core understandings are in place early (e.g., theory of mind), whereas concrete-to-abstract change will result in other areas (e.g., chess). Indeed, such shifts might serve as a method for uncovering children's foundational knowledge domains.

Commonalities across These Early Domains of Understanding

The full story of foundational knowledge acquisition requires the consideration of multiple domains. To examine children's understanding of physics, it is necessary to consider an alternative domain such as psychology; to examine biology, it must be contrasted with physics and psychology. Comparisons across these domains of thought also raise intriguing questions. Consider the claim that in these three domains, children easily appeal to unobservable entities. Does this represent the workings of a domain-general learning assumption—a general essentialist assumption, say, that all phenomena have underlying essences? Or do we have three different domain-specific assumptions, one tied to the essences underlying biological categories, one to the mental states underlying behavior, and one to the forces and entities (centers of gravity, insides, and atoms) underlying physical matter and events?

In part, we argue that apparent uniformity across domains, when it occurs, is more apparent than real; children are developing distinctive domain-specific notions that are similar only by adopting a quite general level of analysis. But in part, language as a system of understanding may also be influential. Language is a domain in its own right—a system of regularities, meaning-form matches and mismatches that children work on and restructure. That is, regardless of the specific characterization of the language domain—for example, in terms of innate modules (Pinker, 1994) or in terms of a functional expertise (Tomasello, 1995)—it certainly seems plausible to argue that language and communication constitute a domain of knowledge separable from naive physics, psychology, and biology. Although it is separate, language understanding can nonetheless contribute to knowledge acquisition in other domains, just as an understanding of naive psychology can be employed by analogy to understand other complex devices—computers, thermostats (Carey & Spelke, 1994). Indeed, one of the most fruitful domains for this sort of influence, at least early in development, may well be language. At the age that children are acquiring naive physics, psychology, and biology, they are rapidly acquiring language as well. Even minimal communicative competence permits social transmission of information about the physical, psychological, and biological worlds. Moreover, languages universally have certain conceptual presuppositions: They parse up the world into objects, events, and properties (roughly, nouns, verbs, and adjectives); nouns label kinds that may be presumed to share common features; categories are organized into class-inclusion hierarchies; animacy is highly predictive of which kinds of things are most likely to be the subjects of verbs or to take certain kinds of markers (such as gender); languages agree more or less as to which sorts of things are more or less animate (Silverstein, 1976); and there is a conceptually basic sentence structure common among children across the world—an animate agent is performing an action on an inanimate object. (See Comrie, 1981; Croft, 1990; Greenberg, 1966; Slobin, 1985 for a rich set of conceptual properties embedded in language.)

Thus, to illustrate, a search for unobservable essences may be a consequence of the logic of nouns (Carey, 1995; Mayr, 1991): Nouns impose categorical structure on the world. Our strong intuition that all dogs are in some deep sense the same may derive unconsciously from the forms of language: We say that a chihuahua is a dog, an Irish Setter is a dog, and a poodle is a dog. The implication is that these outwardly distinct entities are the same in some important sense. Languages encourage this assumption, not only in the sense of informing children which specific instances fall within a particular category, but perhaps also more generally by employing nouns. In the future, it will be necessary to consider more comprehensively how children's acquisition of language influences their knowledge acquisition in the domains we have reviewed.

Mechanisms in Children's Acquisition of Foundational Knowledge

Expertise

To a degree, the picture that emerges from the research we have considered is one of several domains of early expertise. In these areas, children seem like experts in that they possess considerable knowledge, they recognize underlying nonobvious constructs, they are able to reason logically, and their special attention to phenomena within these domains facilitates the practice and experience that underwrite additional learning and an enriched knowledge base.

However, traditional expertise accounts fall short in several ways. Somewhat ironically, expertise accounts seem intrinsically domain general. Practice and experience as applied to any area of knowledge yield expertise; witness experts of such contrived subjects as baseball, chess, and the Beatles. General processes of memory, information acquisition, information organization, and inference are often posited to produce experts. The picture is one of a level conceptual playing field that only differentiates according to the dictates of experience and practice. However, children appear to be more easily expert in some domains than others—such as naive physics versus reading. A challenge to expertise accounts, therefore, is to explain why some kinds of expertise are easy for even young humans to acquire. One possibility consistent with an expertise account is that the domains we have reviewed may include the kinds of things parents most often talk about, the sorts of objects children most often encounter, the modes of explanation a culture finds most useful, and the experiences children (and adults) find most interesting. However, this argument becomes circular without a means of explaining why children and adults have these preferences and interests to begin with.

A deeper challenge is that expertise accounts are typically bottom-up in character. Experts must build up, then work from, a large store of specific facts and observations. Experts do not merely reason well—they know a lot. As just noted, however, at least in the three domains we have reviewed, development seems to proceed as much from abstractions to specifics as the reverse. As we would put it, children seem to have something like framework theories before they hold specific theories. Thus, from an expertise account alone, young children seem like strange mixtures—grasping certain basic frameworks but often without knowledge of the facts and particulars that seem so implicated to adults. It may even be that parents' and researchers' common experience of seeing children as precocious yet ignorant, both wise and witless, stems from this mismatch between children's knowledge and our common sense expectations of expertise.

Modules

Characterizing these three domains of knowledge in terms of innate conceptual modules can answer the question of why expertise arises so early and rapidly: Evolution has shaped the human mind to attend to and represent these domains in special ways. Modular accounts also provide an obvious explanation for why knowledge in these domains might be resistant to change and to instruction: The way that modules mandatorily convert certain inputs into particular representations precludes serious revision. Two strengths, therefore, of nativist modular accounts are their ability to account for very early knowledge and their ability to account for developmental continuities. An additional strength of modular approaches is that they exploit and develop links between cognitive development, cognitive neuroscience, and evolutionary psychology (see e.g., Baron-Cohen, 1995).

In terms of mechanisms, modular accounts are notably parsimonious. The initial emergence of representations and subsequent conceptual change have the same explanation—the relevant module comes on line. Note, however, that on this explanation the sources of change are all exogenous, outside the conceptual system itself. Conceptual change is due to brain maturation rather than either the accumulating effects of information or reorganizations in the content and structure of concepts themselves. Cognitive development reduces to neurological development. It seems undeniable, however, that other factors account for conceptual revisions; at the very least, they do so in the course of intellectual history. Einstein's theory of physics represents a radical departure from Newton's, yet we do not account for this change by neurological mechanisms—an Einsteinian mental module coming on line historically. Rather the explanation for these conceptual changes, whatever their specifics might be, is couched in part in terms of developments within the system of relevant concepts themselves; the later theory builds off of but revises the earlier one. It is an empirical question whether the changes that characterize ontogenetic development include the sorts of endogenous conceptual transformations that can be seen in historical development; but many scholars argue that they do (e.g., Carey, 1985; Gopnik & Wellman, 1994; Karmiloff-Smith, 1992; Munakata, McClelland, Johnson, & Siegler, in press; Piaget, 1954; Plunkett, 1995).

Relatedly, a major question continues to be how much and what sorts of conceptual restructuring are apparent in children's understanding of the world. To reiterate, modules once on-line automatically convert their proprietary inputs into mandatory representations, hence, those representations are essentially unrevisable. Modular accounts of this sort thus allow no fundamental changes in the child's basic concepts themselves, only enrichment or extension of the existing mandatory notions and removal of performance obstacles to the demonstration of innate conceptions. A challenge to such accounts, therefore, is the demonstration that fundamentally new or revised conceptual systems can develop. Take Spelke's (1994) core notions of physical objects as solid and moving on continuous paths. She posits that these early notions fundamentally constrain the cognizable entities in the domain of physics and thus that these notions not only capture infant conceptions of objects but also "constitute the core of mature knowledge." Yet expert physicists' core notions are radically different—space and time merge, objects act on objects at a distance, and so on. Of course, such conceptions were difficult to come up with historically, are difficult to convey to students and novices even in the present day, and likely co-exist with, rather than displace, more everyday conceptions of the physical world in the mind of any individual. But, if Spelke were literally correct, such conceptions would be impossible—never even conceived because they fall outside the confines of our innate conceptual endowment, much as humans can never grow wings, because to do so would fall outside our innate physiological endowment. If any of the claims reviewed in this chapter of developmental conceptual revolutions regarding objects, minds, and biology are even approximately correct, they pose major challenges to an innatist modular approach.

A final related challenge to innatist modular theories comes from an expansion of evolutionary arguments themselves. Some writers argue that an evolutionary account of cognition requires a modular view of the mind (Cosmides & Tooby, 1994). Other evolutionary accounts focus on the evolution of cognitive complexity and flexibility (e.g., Bennett & Harvey, 1985; Gould, 1977). Organisms have evolved not only definite structures to cope with particular tasks—for example, wings to exploit aerial ecological niches, imprinting to attach offspring to parent—but they have evolved ways for their offspring to put off adapting until born into the specific environment they find. Learning in its myriad forms is the prime example. Humans in particular are characterized by a long period of childhood that allows for learning and ontogenetic rather than phylogenetic adapations. Relatedly, Tomasello, Kruger, and Ratner (1993) have recently argued that humans have evolved several special social-cognitive abilities that allow for and account for cultural learning. These abilities lead to the creation and use of cultural tools such as language, mathematics, and science, and also to specific cultural systems of meaning and interpretation. Tomasello et al.'s is only one proposal among many (e.g., Bruner, 1990; Cole, 1988; Rogoff, 1990; Vygotsky, 1978). Our point here is that human children have evolved to be able to change conceptually and thus are able to adapt and contribute to changing knowledge. Indeed, Gopnik and Wellman (1994) go so far as to suggest that our adult capacity for scientific discovery, as well as for lifelong education, may well be a holdover of our capacities as children to engage in fundamental conceptual construction and learning—a sort of cognitive neotony. At the very least, modular proposals need to specify more clearly how to account for such varied and flexible innovation and learning, given only an architecture of nonrevisable innate conceptual modules (e.g., Sperber, 1994).

Theories

In some senses, theory-theory accounts stand between modules and expertise. Like modular accounts, they posit early conceptual structures that determine representation and understanding. Like expertise accounts, they emphasize change and the fit between resulting conceptual structures (theories) and evidence or experience (data). The theory theory is not simply a compromise position between modular and expertise views, however; it is a specific proposal with its own detailed positions. For example, in their construal of cognitive structures as theory and their acceptance of early innate concepts, theory-theory proposals are quite unlike Piaget's: There is no denial of rich innate structure and thus no recourse to action as the necessary well-spring of conception. There is no insistence on domain-general logical stages that are independent of specific contents. Rather, theories are domain-specific, content-full structures that are shaped by the acquisition of knowledge in the domain itself.

In their construal of cognitive change as like theory change, however, theory theorists reaffirm some of Piaget's proposals. Specifically, Piaget insisted on and attempted to characterize the relation between abstract cognitive structures, input from the experiential world, and newly revised structures. Assimilation and accommodation were, in part, his mechanisms for this process. Characterizing cognitive change in terms of theory change confronts this same problem. Theories are structures based on interpreting evidence; evidence speaks to old theories and can transform them into new ones. But how, more precisely? One challenge for theory theories is to articulate and model how such a process of conceptual revision works. How do structure and experience interpenetrate; how do theories and data influence each other in the unfolding of individual cognitive development? These are difficult questions. It is noteworthy, however, that the question of how to characterize conceptual acquisition and change is reasonably simple for either modular or expertise perspectives. Those accounts have straightforward, albeit sometimes complex, answers—new concepts either emerge innately or are governed by domain-general learning processes. In contrast, the theory theory must confront more directly the problem of specifying the mechanisms for conceptual change. Assimilation and accommodation proved too vague; theory theories may flounder on the same issue.

One attraction of the theory theory, as we see it, is the distinction between *specific* versus *framework* theories. Framework theories are neither domain general, as are Piaget's logico-mathematical structures, nor are they small corners of experience such as skill domains (e.g., chess). Despite its considerable scope, for example, a theory of mind explains only mental things, not physical things. In one way or another, scholars of cognitive development are finding the need to characterize such framework understandings. Related proposals include R. Gelman's skeletal principles that define domains (1990), Mandler's global rather than specific categories (e.g., Mandler, Bauer, & McDonough, 1991), Simons and Keil's (1995) abstract concepts that precede rather than result from concrete understandings, and Case's (1992) central conceptual structures. A consideration of framework theories, we believe, helps pose and address questions about such structures.

As just one example, a large problem for discussions of domain-specificity continues to be, what domains are there? There is no tidy answer here as yet, but theory theory offers a process for addressing the question. Each framework theory defines its own domain. Identifying the domains of human cognition thus is an empirical question, answered by identifying the framework theories. Moreover, such theories evolve and one can differentiate out of another, so there is nothing to say that human domains need to carve up the world in some tidy, comprehensive, developmentally stable, or philosophically elegant, fashion.

If the early developments we have reviewed are framework theories, however, it seems curious that children seem to be acquiring at least two and perhaps all three of these theories on such an apparently similar timetable. Certainly the history of science gives no reason to expect the development of physics, psychology, and biology to proceed along similar timetables. Empirical studies of naive psychology, biology, and physics have almost never attempted detailed comparisons of understandings across these domains; the findings only suggest a rough parallelism in that knowledge in all three domains emerges rapidly in the early years. Gopnik and Meltzoff (1997), however, describe a theory-theory account of young children's understanding of objects, of human actions, and of classes during the time period of birth to about 2 years. They argue that sizable conceptual revolutions in each of these domains takes place at about 9 to 12 months. If this developmental description is correct, it underscores the challenge we are raising here: Nothing in theories and theory development per se suggests that three such different strands of conception should develop on similar timetables. To the contrary, if theories are separate, content-dependent structures, and theory developments require separate content-dependent experiences, it would be a striking coincidence to find such similar developmental milestones.

Other Proposals and Processes

Theories, modules, and expertise certainly do not exhaust ideas about mechanisms of cognitive change. In recent years, we have witnessed a renewed interest in the mechanisms of cognitive development, along with a number of substantive and methodological proposals (e.g., Karmiloff-Smith,1992; Mandler, 1988; Ribaupierre, 1989; Rogoff, 1990; Siegler, 1989; Sternberg, 1984). At a more general level, several writers have argued for a general reorientation in our thinking about mechanisms (Bertenthal, 1996; Plunkett, 1995; Siegler, 1989, 1995). These writers, among others, note that cognitive-developmental research has yielded a wealth of descriptive information about children's thoughts at different ages, yet much less information about how cognition changes. Part of the problem, they suggest, is an emphasis on consistency rather than variability. There are at least two problems with insisting that "children of a given age think about a task in a given way" (Siegler, 1995, p. 406). First, it makes the conceptualization of change hard—if children's thinking is all of one sort at one age and then becomes different, "why would they suddenly form a different understanding?" (p. 407). Second, empirically, such descriptions seem wrong: Findings concerning children's strategies, concepts, and problem solutions suggest that performance is quite variable. Not only do individuals differ, but more importantly, each individual shows a mix of alternative, even contradictory procedures at any one time. Using microgenetic methods (cf. Kuhn & Phelps, 1982), Siegler has studied computational strategies—how children solve arithmetic problems—and documents that children exhibit multiple strategies which advance and recede over time. More generally, cognitive change exhibits processes of competition between ongoing alternatives (see also MacWhinney, 1987). Successful procedures compete with and overtake less successful ones, new strategies emerge as variants of old ones, conceptual construals conflict with one another. Microgenetic methods often focus on these variations as well as allow researchers to examine the process of change in more detail from repeated measurements within a relatively brief period of time (Kuhn, Garcia-Mila, Zohar, & Andersen, 1995; Siegler & Crowley, 1991).

The research we have reviewed could both fit with and amplify this sort of thinking about cognitive change. First, children are developing several alternative conceptual frameworks—not just a monolithic understanding of the world, but rather distinctly physical, psychological, and biological construals. Even to young children, animals are both animate *and* physical objects; persons are not only psychological entities, but biological and physical entities as well. These alternative systems provide children with the sorts of conceptual multiplicity required to afford processes of cognitive competition; knowledge from multiple domains multiplies children's approaches, strategies, and conceptual resources.

Moreover, it is important to reiterate that by our analysis, children's reasoning within these domains systematically incorporates at least two levels of analysis—one that captures more surface phenomena versus another that penetrates to deeper theoretical levels. Young children see that blackbirds and bats look alike in terms of appearance, yet also realize they are structured differently inside, perhaps that they manifest different essences. Young children distinguish between a person's mistaken belief and the actual state of the world. Young children distinguish between appearances and realities in the realms of objects, animals, representations, and mental states (e.g., Flavell et al., 1986). Essences, underlying mental states, and invisible particles of material substances all reflect children's appreciation of at least two contrasting representations of a situation. Thus, children entertain not only alternative problem-solving procedures, they regularly entertain alternative conceptual perspectives on the world, and such alternatives fuel attempts to compare, share, merge, and create new conceptions. The general point is that if cognitive development requires alternative construals—as highlighted in models of strategy choice, cognitive conflict, disequilibrium, theory change, and analogical reasoning—then these three domains of thought, and children's early framework understandings of these domains, provide several of the needed alternatives.

Culture and Variation

Foundational knowledge might appear early and be formative for later conceptual development, yet still be specific in place and time and dependent on specialized socialization practices. To what extent are the domains of knowledge we have sketched specific to the children of only one culture? This is a question that as yet has no clear answer. However, it is important to point out that a number of the findings we review seem to be common in a variety of English-speaking countries—the United States, Canada, England, Scotland, Australia—and non-English-speaking European countries as well—Austria, the Netherlands, Germany, Turkey. The relatively scarce data available from nonwestern children, such as those from Japan (e.g., Inagaki & Hatano, 1993), and from nonliterate cultures, such as the Baka from the Cameroons (Avis & Harris, 1991), or the Yoruba from Nigeria (Jeyifous, 1986), are typically in accord with the English-speaking data in demonstrating early expertise for these domains of knowledge. Nonetheless, rarely has research precisely targeted nonliterate cultures or cultures hypothesized to contrast in interesting ways with the naive theories evident in western English-speaking countries.

The possibility that cultures vary substantially, even in their basic understandings, is important to consider in all three domains we have reviewed, but it is especially easy to illustrate in the domain of naive psychological reasoning (e.g., Lillard, 1995). In this case, anthropologists have made explicit ethnographic claims that adults in some cultures understand persons in decidedly different ways from a Western belief-desire construal.

> The most challenging and interesting thing about the Baining from the point of view of ethnopsychological studies is that they appear not to have a folk psychology. The Baining exhibit a pervasive avoidance of modes of discourse about psychology. If we understand the latter to be a domain of culture which includes a concern with affect and emotions, concepts of person and self . . . interpretations of behavior, and ideas about cognition and personality development, the Baining manifest very little interest in these areas. (Fajans, 1985, p. 367)

At the moment, it is possible either that basic mental state reasoning (of some characterizable sort) is a human universal (although unremarked in certain ethnographic reports designed to probe cultural differences), or that there are no universal, foundational, folk psychological conceptions of the mind; instead, each culture socializes its children into quite different understandings.

We believe that demonstrations of early understandings of the sort we have reviewed, are particularly relevant to these unfolding discussions. Consider again naive psychology. If a mentalistic belief-desire understanding in our culture is the endproduct of extensive enculturation and socialization, it is easy to imagine alternative cultures with a very different sort of end product. On the other hand, if very young English-speaking children begin the process of person understanding with the assumption that persons have internal mental lives, it is easier to imagine that social understanding in all cultures might honor this assumption in one form or another. Very young English-speaking children, we argue, approach the task of learning about persons, and acquiring the vocabulary for actions, emotions, reactions, and mental states, with certain framework assumptions. In particular, they begin by interpreting persons in internal, mentalistic fashions and assuming that certain terms refer to those nonobvious states and experiences rather than or in addition to bodily movements or facial displays. Similarly, they quickly adopt initial framework understandings for physical objects and for certain biological phenomena. Certainly, as we have outlined in this chapter, it is impressive how rapidly young English-speaking children can understand and talk about such phenomena so appropriately—including nonobvious aspects and underlying constructs.

Again this hypothesis—that young children have impressive foundational knowledge—argues only for the existence of very general frameworks within which children still must engage in much culture-specific learning. On the one hand, the hypothesis predicts certain constraints on folk theories across cultures, deriving from framework assumptions present in children and continuing in adults. On the other hand, such constraints may be enabling as much as constraining, because they operate developmentally. As *framework* understandings, young children's early physical, psychological, and biological notions must necessarily be fleshed out, and these early notions may develop in a variety of fashions to constitute quite different specific theories. In the extreme, cultural communities have centuries in which to develop their own specific theories. And such communities have many years—at the least, from infancy to adulthood—in which to train and enculturate each member into an ethnotheory. The result may well be a host of ethnotheories quite different from one another and from the initial assumptions of 2- and 3-year-olds.

This sort of analysis suggests that young children's understanding in core domains may be more similar across a variety of cultures and languages than is adults' understanding. This is not a new idea. Mead (1932), in her study of children's understanding of causality in Manus, argued that these children had a straightforward physicalistic understanding of events, such as a canoe going adrift. Just like adults (and, we contend, children) in Western English-speaking societies, children in Manus explained such events in terms of commonplace physical events, such as ropes unfastening, or the water's currents. But adults in Manus explained such events in terms of ghosts, evil intents, and animistic forces. Similarly, Kohlberg (1969) argued that the dream concepts of American and Atayal children were quite similar until age 6 or 7. Only after that point did American and Atayal judgments differentiate, with older children and adults in each community holding to two dramatically different conceptions—in the one case, that dream events are internal, mental phenomena and in the other, that they are real, visible, external phenomena. Harris (1990) has argued that young children's understanding of persons and minds may show basic commonalities across cultures that become submerged in or replaced by very different elaborated adult ethnotheories.

Alternatively, young children in different cultures may acquire very different frameworks rapidly, as the result of early and rich enculturation (see e.g., Lillard, in press). In any event, the existence of early foundational knowledge in some children argues for the need for research across a wider array of cultures and experiences.

Final Remarks

Research on foundational knowledge systems has exploded in the last several years, with studies of infants' and children's understanding of physical, psychological, and biological phenomena leading the way. The intensified interest in knowledge systems has several sources: a rediscovery of the importance of domains of thought in everyday life; conceptual analyses of the domains themselves—their core principles, naive theories, coherent knowledge systems; and, empirical studies that cleverly tackle these topics, revealing sense, structure, and development in these areas, and thus inspiring further research. These areas of knowledge acquisition, individually and together, have proven fertile ground for advancing and testing basic accounts of cognitive development, including modular, expertise, and theory-theory positions. The work brings into focus our ignorance as well as our knowledge. This is a sign of scientific good health: A mix of agreement and disagreement, known and unknown, knowledge gained and knowledge sought, seems especially fitting for a field whose substantive topic is knowledge acquisition itself.

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