This child’s concept of lunch clearly differs from that of older children and adults. But what can we conclude from the difference? Is it simply an isolated confusion between typical and essential characteristics of lunch? Or is it symptomatic of a more general tendency of younger children to understand concepts superficially and not to grasp their core meaning?

Concepts involve grouping together different entities on the basis of some similarity. The similarity can either be quite concrete (a concept of dogs) or quite abstract (a concept of justice). Concepts allow us to organize our experience into coherent patterns and to draw inferences in situations in which we lack direct experience. If told that malamutes are dogs, a child immediately also knows that they have four legs, a tail, and fur; that they are animals; that they probably are friendly to people; and so on. Concepts also save us mental effort, by allowing us to apply previous knowledge to new situations. Once we have the concept “kitten,” we do not need to think hard about this particular scrappy, taffy-colored kitten to guess what she would like to eat.

The tendency to form concepts is a basic characteristic of human beings. Infants form concepts even during their first months (Haith & Benson, 1998; Quinn & Elms, 1995). Within a few years, children acquire a huge number of concepts. Consider a few that most 5-year-olds in the United States possess: tables, gold, animals, trees, Nintendo, dirt bikes, running, birthdays, winter, fairness, time, and number. Some of these concepts involve objects, others events, others ideas, others activities, and yet others dimensions of existence. Some of the objects are part of nature; others are artifacts made by people to serve a specific purpose. Some of the concepts are possessed by children throughout the world and have been throughout history. Others are specific to children living in advanced industrial societies of the late twentieth century. Some are broadly applicable; others are quite narrow.

In this chapter, we look at conceptual development from two perspectives. One focuses on conceptual representations in general; the other focuses on the development of a few particularly important concepts (Table 8.1).

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**TABLE 8.1** Chapter Outline

<table>
<thead>
<tr>
<th>I. Conceptual Representations in General</th>
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<tbody>
<tr>
<td>A. Defining-Features Representations</td>
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<td>B. Probabilistic Representations</td>
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<td>C. Theory-Based Representations</td>
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<th>II. Development of Some Particularly Important Concepts</th>
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<tr>
<td>A. Time</td>
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<td>D. Biological Concepts</td>
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| III. Summary                                           |
TABLE 8.2 Classic Characterizations of Older and Younger Children's Concepts

<table>
<thead>
<tr>
<th>Description of Younger Children's Concepts</th>
<th>Description of Older Children's Concepts</th>
<th>Theorists(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Abstract</td>
<td>Piaget (1951)</td>
</tr>
<tr>
<td>Perceptual</td>
<td>Conceptual</td>
<td>Bruner, Goodnow, &amp; Austin (1956)</td>
</tr>
<tr>
<td>Holistic</td>
<td>Analytic</td>
<td>Werner &amp; Kaplan (1963)</td>
</tr>
<tr>
<td>Thematic</td>
<td>Taxonomic</td>
<td>Vygotsky (1934/1962)</td>
</tr>
<tr>
<td>Global</td>
<td>Specific</td>
<td>Inhelder &amp; Piaget (1964)</td>
</tr>
</tbody>
</table>

The approach that emphasizes the development of conceptual representations in general is based on the assumption that the nature of people’s minds leads them to represent most or all concepts in a particular way. The nature of this representation is of primary interest; the details of the particular concepts are secondary. This approach has been most common in studying object concepts such as tools, furniture, and vehicles, where the particulars of the concept are less important than the concept’s representativeness.

If the nature of people’s minds leads them to impose a certain type of representation, and if young minds differ fundamentally from older ones, then young children’s concepts may also differ fundamentally. For example, their concepts may be concrete, whereas those of older children may be abstract. Many of the most prominent developmental theorists have subscribed to this representational development hypothesis. Table 8.2 lists some of the contrasts between younger and older children’s concepts that have been proposed.

The other main approach has been to focus on the development of a few inherently important concepts. Certain concepts, such as time, space, number, and living things, are so basic to our understanding of the world that their development is important in its own right. These concepts have played central roles in the theories of philosophers such as Kant and psychologists such as Piaget. They also may develop differently than other concepts. Unlike most concepts, they are largely universal across cultures and historical periods, they are present in rudimentary form in infancy, and they are constantly used. It is hard to imagine how people could learn such concepts if there were not some relatively specific biological basis for them. For example, if people did not encode events as occurring before or after each other, what experiences could lead to their doing so? Understanding of these basic concepts often changes dramatically during development, but their core seems to be part of our inheritance as human beings (Spelke, 1994, 2000). In the sections that follow, we first consider the development of conceptual representations in general and then the development of a few particularly important concepts.

Conceptual Representations in General

How do people represent concepts? Three main possibilities have been proposed: defining-features representations, probabilistic representations, and theory-based representations. The differences among the proposed representations can be seen in the depictions of the concept “uncle” in Figure 8.1. Defining-features representations are like dictionary definitions. They include only the necessary and sufficient features that determine whether an example is or is not an instance of the concept. Probabilistic representations are more like the articles in encyclopedias. Rather than just representing a few features that must always be present, people may represent concepts in terms of a large number of properties that are somewhat, but not perfectly, correlated with the concept. Thus, uncles tend to be nice to their nieces and nephews, though they are not necessarily so. Finally, theory-based representations are akin to chapters in a science textbook, in that they

FIGURE 8.1 Ways in which the concept “uncle” might be represented within defining features, probabilistic, and theory-based approaches.

<table>
<thead>
<tr>
<th>Representation</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defining Features</td>
<td>Father’s or Mother’s Brother or Aunt’s Husband</td>
</tr>
<tr>
<td>Probabilistic Features</td>
<td>Brother of Father or Mother or Husband of Aunt</td>
</tr>
<tr>
<td></td>
<td>About as Old as One’s Parents</td>
</tr>
<tr>
<td></td>
<td>1.0 Nice</td>
</tr>
<tr>
<td>Theory-based</td>
<td>Uncle</td>
</tr>
<tr>
<td></td>
<td>Handsome</td>
</tr>
<tr>
<td></td>
<td>Father’s or Mother’s Brother or Aunt’s Husband</td>
</tr>
<tr>
<td></td>
<td>Therefore</td>
</tr>
<tr>
<td></td>
<td>About Same Age as Parents</td>
</tr>
<tr>
<td></td>
<td>Therefore</td>
</tr>
<tr>
<td></td>
<td>Loves Mommy or Daddy</td>
</tr>
<tr>
<td></td>
<td>Therefore</td>
</tr>
<tr>
<td></td>
<td>Loves Me</td>
</tr>
</tbody>
</table>
emphasize causal relations among elements of a system. Children's conceptual representations may include explanations for why their uncles tend to be nice, why they tend to be about as old as their parents, and so on.

Are young children capable of generating all of these types of representations? As previously noted, some of the most eminent developmental theorists—Piaget, Vygotsky, Werner, and Bruner, among others—thought not. Although they used different terminologies, all hypothesized that young children cannot form what we are calling defining-features representations. We next consider the evidence on which they based this view and whether they were right.

DEFINING-FEATURES REPRESENTATIONS

What would it mean for people to represent concepts in terms of defining features? First, they would know the concepts' necessary and sufficient features. Second, they would use these features to determine whether particular examples were instances of the concept.

Piaget, Bruner, and others based their view that young children could not form defining-features representations largely on observations of children playing with objects. They presented children several types of objects, such as toy animals, vehicles, and furniture, and observed which ones children put together. They found that younger children typically divide the objects into categories with a defining feature: They put animals with animals, vehicles with vehicles, and so forth. In contrast, a typical preschooler might put together a dog and a car (because dogs like to ride in cars), a cat and a chair (because cats like to curl up in chairs), and a game and a shelf (because games belong on shelves). Such groupings led Inhelder and Piaget (1964) to conclude that preoperational stage children's concepts were thematic (organized in terms of a common activity or theme), whereas concrete operations stage children's concepts were taxonomic (organized in terms of hierarchically organized categories, like those used to classify plants and animals in biology).

Vygotsky (1934/1962) used a similar task to study conceptual development. He presented children a number of blocks that differed in size, color, and shape, and asked them to group together those that went together. Children ages 6 years and older who were given this sorting task typically chose a single quality as the defining feature. For example, they might choose color as necessary and sufficient for membership in a group, and put all the red blocks together, all the green blocks together, and so on. Preschoolers, however, seemed to form what Vygotsky called chain concepts. These were concepts in which the basis of classification changed from example to example. They might put together a few red blocks; then put a few triangular blocks, green as well as red, together; and then put a few green blocks together.

These types of observations led Vygotsky to hypothesize that children pass through three stages of conceptual development. Very early, they form thematic concepts, stressing relations between particular pairs of objects. Later, they form chain concepts by momentarily classifying on the basis of abstract dimensions such as color or shape, but often forgetting what they were doing and switching the basis of their categorization. Still later, during the elementary school period, they form true concepts, based on stable, necessary, and sufficient features.

Evaluation. The defining-features view of concepts has led to a number of discussions about preschoolers' conceptual understanding: that they often do not sort objects along a single consistent dimension; that they tend to arrange objects according to how the objects interact, rather than according to their categorical relations; and that they find different relations of interest than do adults.

But should we believe the broader theoretical claim that young children's concepts differ fundamentally from those of older children and adults? Probably not. Research conducted to test whether young children can form types of concept typical of older children has consistently shown false. For example, Bauer and Mandler (1989a) found that even 1-year-olds form taxonomic concepts. They presented children of this age with sets of three objects. The target object was placed in the middle, and children were asked, "See this one? Can you find another object just like this one?" Of the remaining two objects, one was related to the target object thematically and the other taxonomically. For example, in one problem, the object in the middle was a monkey; the object related to it taxonomically was a bear, and the object related to it thematically was a banana. The 1-year-olds chose the taxonomically related objects (the monkey and the bear) as being the similar ones on more than 85 percent of trials.

If even 1-year-olds understand taxonomic relations, why would the impression have arisen that 4- and 5-year-olds cannot understand them? Confusing children's interests with their capabilities may be the reason. Young children may put dogs and frisbees together, rather than dogs and bears, because they find the relation between dogs and frisbees more interesting. Supporting this interpretation, Smiley and Brown (1979) found that preschoolers who sorted objects thematically could, when asked, explain perfectly the taxonomic relations as well. Other studies have documented flexible use of both thematic and taxonomic categories in preschoolers. These studies suggest that children's tendency to use one type of concept or the other depends on the context in which the task is presented (Blaye & Bonthoux, 2001) or on the nature of the task instructions (Waxman & Namy, 1997). Cole and Scribner (1974) reported similar findings with tribespeople in Africa. Experimenters could elicit more sophisticated taxonomic sortings from the tribespeople only by asking, "How would a stupid man do it?" Both the children and the tribespeople possessed the relevant concepts, but they chose not to apply them in the particular situation.

Another contributor to the misperception has been understimating the role of specific content knowledge in conceptual understanding. Although young children represent some concepts in terms of defining features, they do not know what the defining features are for other concepts. Consider an experiment
TABLE 8.3 Stories from Keil and Battersman (1984)

<table>
<thead>
<tr>
<th>Characteristic Features But Not Defining Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>There is this place that sticks out of the land like a finger. Coconut trees and palm trees grow there, and the girls sometimes wear flowers in their hair because it’s so warm all the time. There is water on all sides except one. Could that be an island?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Defining Features But Not Characteristic Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>On this piece of land, there are apartment houses, snow, and no green things growing. This piece of land is surrounded by water on all sides. Could that be an island?</td>
</tr>
</tbody>
</table>

in which 5- and 9-year-olds heard two stories describing a particular object and then were asked whether that object could be an example of a particular concept (Keil & Battersman, 1984). As shown in Table 8.3, one story indicated that the object included many features people associate with the concept, but also indicated that it lacked the defining feature. The other story indicated that the object included the defining feature, but lacked many associated features.

The 9-year-olds generally emphasized the defining features; they usually said that the story at the top of Table 8.3 did not describe an island but that the story at the bottom did. The performance of the 5-year-olds was in some ways different and in other ways similar. The 5-year-olds did not rely on the defining feature as many concepts as the 9-year-olds. However, on familiar concepts, such as "robbers," the 5-year-olds did rely on defining features, and on relatively unfamiliar concepts, such as "taxis," the 9-year-olds did not consistently do so. (The fact that the study was conducted in a small town probably had a lot to do with the concept of taxi being unfamiliar. Thus, both younger and older children can form defining-features representations, but knowledge about the defining features of particular concepts increases with age.

PROBABILISTIC REPRESENTATIONS

From the time of Aristotle until relatively recently, most concepts have been viewed as having defining features. Children and adults might or might not know the defining features, but they were there to be known. Today, however, the prevailing view among philosophers is that most concepts do not have defining features. Consider the term "chair." At first glance, a chair would seem to have the defining attributes, "an object with four legs, intended to be used for sitting." But what about beanbag chairs, which have no legs? What about chairs in modern art museums, which never were intended for sitting? The situation is more extreme for complex terms, such as "game" and "mercy." It is difficult to even imagine what the defining attributes might be for such concepts.

These difficulties with identifying defining features open the possibility that all of us, adults as well as children, represent most concepts in terms of probabilistic relations between the concept and various features, rather than in terms of a few defining features. Eleanor Rosch, Carolyn Mervis, and their colleagues have developed an appealing theory based on this view of concepts. The central theme is that instances of most concepts are united by family resemblances rather than by defining features. The instances resemble each other to varying degrees and in varying ways, much like different family members do, but there is no set of features that all of them possess. Rosch and Mervis' theory is built around four powerful ideas: cue validities, basic-level categories, correlations among features, and prototypes.

Cue validities. How might children decide whether objects are examples of one concept or another? Rosch and Mervis (1975) suggested that they do so by comparing cue validities. The basic idea is that the degree to which the presence of a feature makes it likely that an object is an example of a concept depends on the frequency with which the feature accompanies that concept and on the infrequency with which the feature accompanies other concepts. For example, the feature "capable of flight" makes it likely that an object is a bird in proportion to the frequency with which birds can fly and in proportion to the infrequency with which other things can. Because most (though not all) birds can fly, and because most (though not all) other things cannot, flight is a highly valid cue for an object's being a bird.

The idea of cue validities helps the probabilistic approach explain a phenomenon that proved troublesome for the defining-features approach: that some instances of a concept seem like better examples of it than others. Within the defining-features approach, if a robin and an ostrich both have the necessary and sufficient features for birds, why would robins seem like better examples of birds than ostriches? The probabilistic approach suggests that objects perceived as better examples are ones whose features have higher cue validities for that concept. Thus, people view robins as better examples of birds than ostriches, because the robins' color, size, and ability to fly are more valid cues to their being birds.

The cues that people consider in forming concepts change considerably over the course of development. Infants in the first few months are already sensitive to cue validities, but the types of cues on which they focus change with age and experience. Infants initially pay greatest attention to visible and audible features, but with experience, they pay increasing attention to more abstract ones (e.g., Eimas & Quayle, 1994; Madole & Cohen, 1995). There is a reason why infants form categories such as dogs and running but not ones such as tools or fairness.

Despite this early emphasis on perceptual cues, infants' categories are not limited to ones based solely on perceptual features. Even in the first year of life, infants have knowledge about causal and functional attributes of objects that they can use to guide their categorization (Mandler, 2000; Mandler & McDonough, 1993). For example, infants who have been familiarized to a set of artificial-looking
TABLE 8.4 Examples of Superordinate, Basic, and Subordinate Category Members

<table>
<thead>
<tr>
<th>Superordinate Level</th>
<th>Basic Level</th>
<th>Subordinate Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furniture</td>
<td>Table</td>
<td>End table</td>
</tr>
<tr>
<td>Animal</td>
<td>Bird</td>
<td>Canary</td>
</tr>
<tr>
<td>Food</td>
<td>Vegetable</td>
<td>Asparagus</td>
</tr>
<tr>
<td>Tool</td>
<td>Hammer</td>
<td>Tack hammer</td>
</tr>
<tr>
<td>Vehicle</td>
<td>Car</td>
<td>Miata</td>
</tr>
</tbody>
</table>

Toy animals show renewed interest in a toy chair, even if that chair has been painted to be perceptually similar to the animals (Pauen, 2002). Thus, infants appear to use their emerging conceptual knowledge, such as knowledge of the animate-inanimate distinction, in forming categories from an early age.

**Basic-level categories.** Rosch, Mervis, Gray, Johnson, and Boyes-Braem (1976) noted that many categories are hierarchical, in the sense that all instances of one category are necessarily instances of another. They proposed that these hierarchies typically include at least three levels (Table 8.4): a general one (the superordinate level), a specific one (the subordinate level), and one of middling generality (the basic level). The basic level is the level at which cue validities are maximized. For example, "chair" is a basic-level category because it has parts with very high cue validities, among them legs, a back, and a seat. Superordinate categories, such as "furniture," do not have features with comparably high cue validities. Some pieces of furniture have legs and others do not; some are for sitting and others are not. Conversely, subordinate categories, such as "kitchen chairs," share all features of the basic-level category, but lack features that clearly discriminate them from other instances of the basic-level category. What features clearly discriminate kitchen chairs from dining room chairs? Rosch et al. concluded that basic-level categories are more fundamental classifications than either superordinate or subordinate categories.

If basic-level categories are indeed basic, children should learn them before they learn superordinate or subordinate categories. This implication has been tested by presenting infants with a habituation procedure. First, the infants are repeatedly shown members of a basic-level category until they reduce their looking at the objects. Then they are presented either a novel member of the same basic-level category or a member of a different basic-level category within the same superordinate category. For example, they might repeatedly be shown horses, and then be shown either a giraffe or another horse.

Research with 3- to 9-month-olds has consistently shown that infants dishabituate when shown members of a different basic-level category (Colombo, O'Brien, Mitchell, Roberts, & Horowitz, 1987; Quinn, Elms, & Rosenkrantz, 1993; Roberts, 1988). For example, after repeatedly being presented pictures of horses, infants dishabituated when shown similar size pictures of giraffes, zebras, or cats (Elms & Quinn, 1994). However, using the same methods, infants have been shown to form more general categories as well (Behl-Chadha, 1996). For example, when shown several different mammals, 3- and 4-month-olds dishabituated when shown birds, fish, or furniture, but not when shown other mammals. Thus, infants are able to form basic-level categories but also more general, superordinate ones.

Although basic-level categories play prominent roles in early conceptual understanding, some of the particular categories differ considerably from those that adults consider basic. Illustratively, the objects that 1-year-olds label "balls" often include such objects as round candies, round coin banks, and multisided beads. Their "ball" category seems to correspond to the adult category "things that can roll." Mervis (1987) labeled such notions child-basic categories. The particulars of "child-basic" and standard-basic categories often differ, but Mervis argued that the principles by which they are formed are the same. Both young children and adults include in their basic categories objects that can be used to achieve similar functions and that have similar appearances. Differing perspectives on what constitutes an interesting function lead to the differences in the categories that are possessed at different ages.

How do children move from child-basic to standard-basic categories? Grasping the role of perceptually insignificant but functionally important attributes may be critical for making the transition (Tversky, 1989; Tversky & Hemenway, 1984). For example, young children initially ignore the slots in round coin banks and the wicks on round candles and focus on the more perceptually striking round shape. Once the child understands the purpose of the slots and wicks, the conceptual distinctions become easier to understand. In keeping with this interpretation, 2-year-olds can move from child-basic to standard-basic categories if an experimenter identifies perceptually subtle attributes that are critical to category membership and explains the importance of those attributes (Banigan & Mervis, 1988).

**Correlations among features.** Conceptual understanding involves more than knowing the cue validities of individual features. Correlations among features are at least as essential. Features of objects in the world are not randomly distributed but rather tend to cluster together. Things that slither along the ground also tend to have scales, to be long and thin, to be difficult to see in their natural environments, and so on. Fortunately, even 10-month-olds are adept at noting correlations among features and at using the correlations to form new concepts (Younger, 1990, 1993).

**Prototypes.** A fourth concept emphasized by Rosch and her colleagues was that of prototypes. Prototypes are the most representative instances of concepts—that is, the examples that have the highest cue validities. Lassie was
a prototypical dog because she had qualities (such as size, shape, bark) representative of dogs in general.

Infants as young as 3 months abstract prototypical forms. Bomba and Siqueland (1965) showed 3- and 4-month-olds a variety of dot patterns generated by randomly transforming an original "prototype" shape, such as an equilateral triangle (Figure 8.2). During this initial phase of the experiment, infants never saw the prototype. However, exposure to examples derived from the prototype (such as the shapes in the rightmost three columns of Figure 8.2) led infants later to act as if they had seen the prototype as well. When they were shown the prototype along with an unfamiliar pattern, they preferred looking at the other pattern; they acted as if they had seen the prototype often and were bored with it. Over time, as memory for the particular dot patterns decreased but the general concept remained, the 3- and 4-month-olds actually showed more interest in shapes they had seen, but apparently did not remember, than in the prototype, which they had not seen but did "remember." Older children and adults show similar patterns of being more confident that they have seen prototypes, which actually have never been shown, than forms derived from the prototypes, which they have seen (Braunsford, 1979).

**Figure 8.2.** On the extreme left, from top to bottom, the prototypic triangle, diamond, and square are displayed. In each row, increasingly distorted versions of the prototypes are displayed from left to right (after Bomba & Siqueland, 1983). Copyright © 1983 by Academic Press, Inc. Reprinted from Bomba, P. C., & Siqueland, E. R., The nature and structure of infant form categories, Journal of Experimental Child Psychology, 35, 294-328, Copyright 1983, with permission from Elsevier.

**Evaluation.** Viewing conceptual representations in terms of probabilistically related features has much to recommend it. Even in the first year, infants abstract prototypical patterns, form basic-level categories, and notice cue validities and correlations among features. With development, they form increasing numbers of superordinate and subordinate level categories, move from child-basic to standard-basic categories for those concepts on which they started with child-basic categories, and become sensitive to more complex and subtle correlational patterns.

The probabilistic-features approach also has some weaknesses, though. One that it shares with the defining-features approach is vagueness about what constitutes a feature. For example, what features make up the concept "a beautiful face"? The features clearly are more complex than hair of a certain color, eyes of a certain shape, lips curved at a certain angle, a nose of a certain form, and so on. Much more important than these tangible attributes are relations among the features, how they fit together. Yet it is unclear whether relations such as "fitting together" can usefully be viewed as features; given that many of the most beautiful faces strike us as unique, it also is unclear whether they are based on probabilistic relations at all.

Another weakness, related to the previous one, is that the approach does not specify how children determine which features of unfamiliar objects and events they should encode and which they should ignore. As discussed in Chapter 3, determining which features to encode is often quite difficult. Yet, unless children encode the important features and relations, they cannot learn their cue validities.

Some researchers have proposed that infants and children are guided toward encoding relevant features through implicit theories of what is important (R. Gelman & Williams, 1998; Wellman & S. Gelman, 1992, 1998) The role of such theories is considered in the next section.

**Theory-Based Representations**

What concept has the following members: children, portable TVs, jewelry, and photo albums? The question seems bizarre until we hear the answer: things we would take out of the house first in case of a fire. Suddenly, the strangeness of the concept disappears (Barsalou, 1985).

As this example suggests, there is more to concepts than correlations among features or defining features. Concepts also embody theoretical beliefs about the world and the relations of entities to each other. These theoretical beliefs influence our reactions to new information. To understand this influence, contrast your reaction to the statement "Today I saw a car with orange wheels" with that to the statement "Today I saw a car with square wheels." Both situations are novel; people would not have had an opportunity to calculate cue validities or feature correlations for either the orange wheels or the square ones.
Neither is in the least prototypical. Yet our theoretical beliefs lead us to react differently to the two statements. When we hear that a car has orange wheels, we infer that the owner may be a prankingster or a hippie, that the rest of the car may also be brightly painted, and that the car probably functions normally. When we hear that a car has square wheels, we infer that it cannot move, that it was not intended to function normally, and that it may be a sculpture intended to elicit surprise. Such inferences reflect our informal theories about how cars work and why people do strange things.

Kohl (1989, 1994) proposed an insightful theory regarding the role that such informal theories play in conceptual development. The following are among the main principles he suggested:

1. Most concepts are partial theories, in that they include explanations of relations among their parts and of their relations to other concepts.
2. Theories are complexly tied to people's associative knowledge; they do not stand apart from it.
3. Causal relations are basic within these theories; they are more useful than other types of relations.
4. Hierarchical relations also are especially informative.

The import of these assumptions can be illustrated with regard to a hypothetical situation. Suppose a girl was asked, "Why do yaks have four legs rather than three or five?" She might answer that four legs can be moved in pairs, which allows yaks to run relatively fast and still maintain their balance. This answer suggests that the child possesses theoretical understanding that allowed her to go beyond defining features and probabilistically related features to explain why the world is the way it is. The answer also illustrates the relation between associative knowledge and theoretical beliefs, in that it reflects both specific memories of the running of other four-legged animals and an informal theory of how running works. The role of causal relations is evident in the child's explaining four-leggedness in terms of what it allows yaks to do. Finally, the fact that the child knew that she could reason from her knowledge of animals in general to a particular animal, yaks, attests to the usefulness of organizing concepts into hierarchies.

Theoretical understanding is present in concepts of very young children, as well as in those of older children and adults. This is not to say that the understanding is the same at all ages. The accuracy and interconnectedness of the theoretical beliefs, as well as the frequency with which they are relied on, increase with development. Evidence also suggests that at all ages, concepts include both theoretical connections and isolated factual information. However, as theories become increasingly sophisticated, they explain an increasingly broad range of the factual knowledge.

Although people generate many informal theories, a few "core theories" may be especially important (Wellman & S. Gelman, 1992, 1998). In particular, Wellman and Gelman hypothesized that children are predisposed to develop three core theories: one concerning inanimate objects (naive physics), one concerning living things (naive biology), and one concerning the human mind (naive psychology). These core theories are said to organize a great deal of their knowledge about the world and help them in acquiring additional knowledge. As Wellman and Gelman (1998) noted, these three domains are central to basic survival as well as to everyday interactions with others and with the physical world:

Knowledge about other humans enables negotiating social interactions and managing important tasks of mating and child rearing; 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 (Wellman & Gelman, 1998, p. 524).

One of the distinctive characteristics of these core theories is that they differ in the types of causal relations that operate. Consider how we would answer a single question, "Why did X move?", depending on whether we were talking about a pebble, a fish, or a person. With the pebble or any other inanimate object, we would explain the movement by citing physical contact with another moving object, as in "The pebble shot across the road because a truck ran over it." With a fish or other biological entity, we would usually explain movement with regard to the function it serves for the species, as in "Birds fly south to stay warm in winter." With a person, we would explain the movement in terms of the individual's goals, such as "The boy went to the store to buy milk." When do children first possess core theories? Spekile (1994) speculated that infants begin life with a primitive theory of inanimate objects, which she labeled a theory of physics. This theory includes the knowledge that the world is composed of physical objects that are cohesive, have boundaries, have substance, move only when touched by another object, and move in continuous ways through space and time. As one source of evidence, she cited Baillargeon's (1987, 1994) finding that 4-month-olds show surprise when a drawbridge appears to move through another solid object (Chapter 2). She also cited her own findings (Spekile et al., 1992) that 4-month-olds show surprise when objects seem to jump from one point to another without passing through intermediate positions or when seemingly independent objects start moving and stop moving in tandem.

Wellman and Gelman (1998) suggested that the first theory of psychology may emerge around 18 months, and the first theory of biology at around 2 or 3 years. For example, infants, however, have some sense of the differences among inanimate objects, people, and other living things. For example, infants as young as 5 to 8 weeks old imitate mouth movements (such as sticking out the tongue or opening the mouth wide) that are produced by another person; however, they do not imitate similar movements produced by inanimate objects, such as a tube with a "tongue" that can protrude, or a box with a "mouth" that can open on one side (Legerstee, 1991). Infants also show surprise if inanimate objects begin
At what point does such knowledge constitute a “theory”? We address this issue below in the section on children’s biological concepts.

**Evaluation.** The theory-oriented approach to conceptual development is bold and promising. Concepts are at their heart relational; causal relations are often especially critical. Children seem to focus on these causal relations from early in life. Knowing the causal relations helps children encode the most relevant information in a situation. The causal knowledge also helps them to draw inferences, to generalize, and to understand their experience.

The approach raises at least as many questions as it answers, however. One of its limitations is vague definition of what qualifies as a theory. A physicist’s theory of matter differs profoundly from that of a typical adult, much less from that of an infant. Within scientific theories, internal consistency, parsimony, and formalizability are important qualities. None of these qualities is shared by the concepts of infants and young children. Similar problems arise in trying to distinguish core theories from non-core ones.

This vagueness about what qualifies as a theory, and what qualifies as a core theory, has led to different researchers using the term theory in very different ways. Carey (1985) proposed that very young children possess only two theories: a theory of physics and a theory of psychology. She suggested that they eventually differentiate into two roughly a dozen theories, corresponding to major disciplines taught at universities: physics, chemistry, biology, psychology, economics, and so on. In contrast, Keil (1989) argued that concepts in general are theoretical and that young children may have innumerable theories. Without clearer specification of when understanding counts as a theory, and when it counts as a “core” theory, such disagreements are inevitable.

Despite these difficulties, viewing concepts in terms of theory-based representations is a promising approach to conceptual development. Many issues remain to be resolved, but the approach’s emphasis on the role of causal relations within conceptual understanding seems an especially important insight. The propensity to explain our experiences is a basic property of human beings; it plays a central role in many of the concepts we form, both large and small.

**Summary.** What can we conclude about children’s conceptual representations? From very young ages, children seem to be capable of representing concepts in at least three ways: that defining features, prototypically related features, and informal theories. The prominence of these different types of representations within children’s conceptual understanding may change, however. In particular, when children are just beginning to form a concept, probabilistic relations between features and the concept may play an especially large role. Early on for some concepts and later on for others, children form simple theories that involve causal relations, both among different aspects of the concept and between the concept and related ideas. Eventually, for concepts that fit the defining features model, children distinguish between those features that are definitional and those that are only characteristic.

**Development of Some Particularly Important Concepts**

Some concepts are so important, and so pervasive, that they merit special attention. These concepts develop among children in all cultures, and probably at all times in history. All have their origins early in development. All also develop in ways that reflect the influence of the surrounding culture. Among these especially important concepts are time, space, number, and certain fundamental biological concepts, such as living things.

**TIME**

The concept of time includes both experiential and logical aspects. Experiential time refers to our subjective experience of the order and duration of events. Logical time involves properties that can be deduced through reasoning. An event that starts later and ends earlier than another must have taken a shorter time.

Experiential time. Without a sense of the order in which events occur, the world would be an extremely difficult place to understand. It should not be surprising, therefore, that infants in their first year already notice such order. For example, when interesting photos are repeatedly shown in the order “photo on right; photo on right; photo on left,” 3-month-olds detect the pattern and begin to look to the appropriate side even before the photo appears (Haith, Wentworth, & Canfield, 1993). They would not know where to look if they did not encode the order of events.

Similarly, children as young as 4 months of age discriminate between movies run forward and backward that show the effects of gravity on liquids and solid objects (Friedman, 2002; Friedman, Gardner, & Zubin, 1995). Since the events in the movies are identical except for the order in which they occur, the infants must be encoding that liquids and solids are typically higher at the earlier time and lower at the later time, rather than vice versa. Four-month-olds discriminate between movies run forward and backward that show liquid being poured into a glass (Friedman, 2002), and 8-month-olds (though not 4-month-olds) discriminate between movies run forward and backward that show a block being dropped and falling to the floor (Friedman et al., 1995).

Further evidence that infants understand order comes from studies in which infants view sets of actions and have the opportunity to imitate them. By the time infants are 12 months old, they are able to imitate sequences of two ac-
tions in the correct order (Bauer, 1995). Thus, understanding of temporal order seems well established in the first year of life. There is also some evidence that infants are able to estimate the durations of events. Colombo and Richman (2002) exposed infants to a sequence in which a light was presented for two seconds, followed by a dark period of either three or five seconds. This pattern was repeated eight times, and on the ninth repetition the light was omitted. Infants showed a deceleration in their heart rate that was closely synchronized with the time when they expected the light to recur. Thus, it appears that infants can accurately estimate lengths of time a few seconds in duration.

Of course, it is not until much later that children can explicitly estimate the durations of events. By five years, children can estimate durations up to 30 seconds quite accurately, especially if given feedback about the true durations (Fraisse, 1982). Older children become increasingly adept at using counting to help them estimate the intervals. However, counting only produces accurate estimates if the units of time being counted are equal and counting quickly to 10 does not take the same amount of time as counting slowly to 10. Many 5- to 7-year-olds count with units of varying duration, which results in their inaccurately estimating the passage of time when they use counting strategies (Levin, 1989).

Still later developing is a sense of durations stretching over weeks or months. By age 4 years, children begin to gain such competence; they consistently judge an event that happened one week ago to have occurred more recently than one that happened seven weeks ago (Friedman, 1991). Children of this age also accurately judge whether their birthday or Christmas was more recent if one occurred in the recent past (the last 60 days) and the other did not (Friedman et al., 1995). However, not until age 9 do children judge accurately which event was more recent when both occurred more than 60 days earlier.

Understanding of durations that stretch into the future presents an even greater challenge for children. Four-year-olds are generally unable to distinguish the distances of events that will occur in the near future and events that will occur in the distant future. For example, 4-year-olds who were visited one week before Valentine’s Day did not consistently judge that Valentine’s Day would occur sooner than Christmas. The ability to distinguish the distances of future events emerges around age 5, and becomes more differentiated in the ensuing years (Friedman, 2000). Why might understanding of the past develop before understanding of the future? One probable reason is that the quality of children’s memories may provide them with cues about the past (for example, more recent events are remembered more vividly). Such experiential cues are not available for reasoning about the future.

In the early elementary school years, children learn about conventional ways of representing time, such as weeks, months, and years, and these representations begin to play a role in their judgments of future events. Between 8 and 10 years, children begin to accurately judge the distances of future events, such as holidays, by relying on their mental representation of the year (Friedman, 2000).

Logical time. To measure logical understanding of time, Piaget (1969) presented children with two trains that ran in the same direction along parallel tracks; the question was which train traveled for the longer time. Although the two trains started and stopped at the same times, children below 6 or 7 years generally said that the train that stopped farther down the track traveled the longer time, as well as the longer distance and the faster speed. Piaget concluded that preoperational children lacked a logical understanding of time, speed, and distance.

Subsequent studies have replicated Piaget’s observations but cast doubt on his interpretation. For example, when 5-year-olds observe cars moving in circular paths, rather than along straight lines, they have little difficulty deducing from the starting and ending times which car traveled for the greater total time (Levin, 1977). They also show understanding of these logical properties in comparing the sleeping times of two dolls that were said to fall asleep and wake up at the same or different times (Levin, 1982). In these cases, there were no strongly interfering cues, such as unequal stopping points, on which children could base incorrect judgments. It thus appears that 5-year-olds understand the logical relations among beginning, ending, and total time, but that their grasp is sufficiently fragile that interfering cues can lead to their not relying on it.

Young children are not the only ones who do not always use the logical understanding of time, speed, and distance that they possess. Older children and adults have the same problem. Think about this situation: When a race car travels around an oval track, do both its doors move at the same speed? Most adults believe that they do, but in fact they do not. The door toward the outside of the track is covering a greater distance in the same time, and therefore is moving faster.

The reason that the problem is so difficult is that it flies in the face of what Levin, Siegler, and Druyan (1990) labeled the single-object/single-motion intuition. This is the belief that all parts of a single object must move at the same speed. Young children, older children, and college students share this intuition. They all consistently say that all parts of a single object travel at the same speed.

Despite the single-object/single-motion intuition ordinarily persisting at least from third grade through college, it can be overcome through physical experiences that dramatically contradict it. Levin et al. presented sixth graders with a 6-foot-long rod, one end of which was attached to a pivot. The child stood beside the experimenter both held the rod while walking around the pivot on four trials. On two of the trials, the child held the rod near the pivot, and the experimenter held it at the far end; on the other two trials, their positions were reversed. The difference in the speed at which children needed to walk while
holding the inner and outer parts of the rod was sufficiently dramatic for them not only to learn that the outer part moved faster, but also to generalize the insight to other problems in which different parts of a single object moved at different speeds. The physical experience accomplished what years of informal experience and formal science instruction usually fail to do. As one boy said, “Before, I hadn’t experienced it. I didn’t think about it. Now that I have had that experience, I know that when I was on the outer circle, I had to walk faster to be at the same place as you” (Levin et al., 1990). Such physical experiences may help children understand concepts at a deeper level than classroom instruction usually does.

SPACE

From early in life, people, like other animals, encode not just where events occur but also when they occur. Under ideal circumstances, these encodings are very accurate from early in life. For example, as shown in Figure 8.3, when 1-year-olds see a Sesame Street toy buried in a long, thin, sandbox directly in front of them, and then wait while the experimenter smooths the sand, they are very accurate in choosing where to dig for the toy (Huttenlocher et al., 1994).

This basic ability to code space gets us started, but it does not overcome the many complex problems posed by the need to locate ourselves and objects in space. We can represent spatial locations and distances in at least three ways: in relation to our own position, in relation to landmarks, or in relation to an abstract framework (Huttenlocher & Newcombe, 1984). **Ecocentric representations** involve locating objects in relation to ourselves. Thus, a target’s position can be represented as “10 paces to my left.” **Landmark-based representations** locate targets relative to other objects in the environment. Thus, we could represent a location by thinking, “I parked the car on the yellow level near the Section B sign.” **Allocentric representations** locate targets relative to an abstract frame of reference, such as that provided by a map or coordinate system. The name allocentric reflects the fact that within such representations, any position can serve as the center or reference point for thinking about the surrounding space.

**Ecocentric representations.** Piaget (1971) suggested that infants in their first year exhibit a kind of sensorimotor egocentrism. Recall from Chapter 2 that egocentrism refers to young children’s tendency to view the world solely from their own perspective. Piaget claimed that in infancy, the egocentrism is quite literal, and that infants represent locations of objects only in relation to themselves. For example, they might continue to represent an object as being a right turn away from themselves even after they moved to the opposite side of the object, resulting in its now being on their left.

Piaget’s hypothesis was supported by subsequent findings that 6- and 11-month-olds frequently fail to compensate for changes in their own spatial position relative to a toy (Acredolo, 1978). In these experiments, a child is placed in a T-shaped maze and repeatedly finds a toy by crawling straight and then turning in a particular direction (such as to the left) at the intersection. Then the child is moved to the other end of the T-shaped maze and turned back toward the middle, thus requiring a turn in the opposite direction (to the right) to find the toy. Most 6- to 11-month-olds continue to turn in the direction that previously led to the toy. Not until 16 months do children compensate for the change in their position.

However, this sensorimotor egocentrism is not absolute, even at such young ages. Infants’ difficulty in adjusting to changes in spatial position can be mitigated if distinctive landmarks provide cues to the object’s location (Rieser, 1979). Under such conditions, 6-month-olds usually turn in the appropriate direction, even when it differs from the direction that previously led to the toy.

How do infants learn to represent space in a way not tied to their own position within it? Just as experience with self-produced motion helps infants perceive depth well enough to avoid going over the visual cliff (Chapter 5, pp. 178–179), so it appears crucial for learning about space more generally (Campos et al., 2000). Eight-month-olds who crawl or who have had extensive experience in a walker succeed considerably more often in locating objects’ spatial positions than infants of the same age who neither crawl well nor have experience with walkers (Bai & Bentalhal, 1992; Bentalhal et al., 1994). The longer children have been locomoting, the greater their advantage (Kermoian & Campos, 1988).
What is it about self-produced locomotion that leads to this ability to overcome the egocentric perspective? Bertenthal et al. (1994) suggested that when infants crawl, they must continuously update their representation of where they are relative to the surrounding environment. Consistent with this view, when 12-month-olds walk to the other side of a layout and have the opportunity to look at all times at the point where a prize is hidden, they both look at it more then children who are carried and subsequently do better in turning toward the object from the new position (Acredolo, Adams, & Goodwyn, 1984).

Self-produced movement can enhance children’s representation of space even when the space they are representing is not the one through which they are walking. This was learned in a clever experiment on the spatial imagery of 5-year-olds (Rieser et al., 1994). The children were students in the same kindergarten class, but were studied while they were at their homes. Some children were asked to imagine being in their classroom, walking to the teacher’s chair, and turning around to face the class. Then they were asked to point to where various objects in the room would be from that vantage point. Few could do so accurately. However, when children from the same class were asked to imagine the same actions while they actually walked and turned around in their own kitchen or bedroom, their pointing was very accurate. The fact that the walking was in a location far removed from the place they were imagining did not prevent the walking from aiding their imagery. Similar findings were obtained with 4-year-olds and 9-year-olds, and in a location other than the children’s home (a research laboratory). The findings indicate that self-produced movement activates people’s representation of space, even if they are not in the particular space being imagined. More generally, it suggests that the systems that produce motor activity and spatial representations are closely linked (Rieser et al., 1994).

Landmarks. We often give directions in terms of landmarks, as in “You go through the Fort Pitt Tunnel, turn off at the Banksville Road exit, and go south until you hit MacFarlane Road.” We do this because landmarks provide a way of dividing the environment into manageable segments. In a sense, they allow people to apply a divide-and-conquer strategy to solving the perennial problem of how to get from here to there.

Representation of spatial locations in terms of landmarks begins in the first year. As noted previously, 6-month-olds’ representations of an object’s position survive a change in perspective if a distinctive landmark is near the object (Rieser, 1979). People as well as objects can provide such landmarks; 9-month-olds at times use their mothers’ location as a landmark for locating interesting objects near her (Presson & Ihrig, 1982).

The use of landmarks undergoes considerable refinement beyond this initial period (Huttenlocher & Newcombe, 1984; Newcombe, 1989). Before children’s first birthday, only landmarks immediately adjacent to the target lead to accurate location of targets. By about 2 years, landmarks that are more distant from the target also help. By age 5, children can represent an object’s position relative to multiple landmarks, a much more powerful procedure for establishing exact locations. For example, they can represent an object as being midway between two other objects.

Although landmarks help young children locate objects in space, they can also distort their representations of the distances separating objects. Piaget, Inhelder, and Szeminska (1960) reported that preoperational stage children estimate the distance separating objects as smaller when a landmark (another object) is between them than when no such landmark is present. Subsequent studies have confirmed that most 4-year-olds, and about half of 5- and 6-year-olds, show this pattern (Fabricius & Wellman, 1993; Miller & Baillargeon, 1990). Their main difficulty, as Piaget suggested, is that they focus on only one of the segments and mistake the distance within it for the entire distance.

Allocentric representations. Frequently, barriers or sheer distance prevent us from seeing our intended destination. Such situations demand integration of spatial information from multiple perspectives into a common abstract representation. Such representations are perhaps the most purely spatial of the three types. Egocentric and landmark-based representations can be easily reduced to a verbal form (as in, Wrigley Field is to my left; the restaurant is near DuPont Circle). In contrast, allocentric representations, which include all relations among the entities within the space, are very difficult to describe verbally.

Although intuition suggests that forming such allocentric representations is more challenging than relying on landmarks, 1-year-olds rely on allocentric representation in some situations in which they do not use landmarks. This was demonstrated in a study by Hermer and Spelke (1994), using a room like the one diagrammed in Figure 8.4. Participants were tested in a rectangular room, with a red barrier in front of each corner. They saw a toy hidden in one corner of the room, were blindfolded and turned around 10 times, and then needed to locate the hidden object.

**FIGURE 8.4** Diagram of room used to study infants’ searching in Hermer and Spelke (1994). The "X" marks the spot at which the object was hidden; the only difference between the conditions was that in the room diagrammed on the right, one wall adjoining the hiding location was blue, thus providing a landmark for locating the hidden object.
the hidden object. Sometimes all four walls of the room were white; in this condition, participants needed to rely on allocentric representations, since no landmarks were present, and twirling blindfolded and stopping at an unknown point would have disrupted their initial egocentric orientation. Under these conditions, the best performance possible was to form a representation based on geometric properties of the space, equivalent to “the toy is in a corner with a long wall on the left and a short wall on the right.” Use of such a representation would lead to equal numbers of searches at the two corners that fit the description (Figure 8.4). This is what both 1-year-olds and adults do.

In another condition, a landmark was established, either by putting a blue cloth on one of the walls next to where the object was hidden or by putting a teddy bear there. Adults used these landmarks to guide their search consistently to the corner where the object was hidden. In contrast, the 1-year-olds were oblivious to the landmark. As previously, they searched predominantly in one of the two corners with the long and short wall in the proper positions, but they searched equally often in the two corners that fit that description. The finding suggests that from early in development, children have a basic allocentric sense of space and use it to orient themselves, even in situations in which they cannot use landmarks to supplement it.

However, a follow-up study by a different team of researchers indicated that 1-year-olds can use landmarks to supplement geometric information. Learmonth, Newcombe, and Huttenlocher (2001) tested children in an all-white room with various types of landmarks (a bookcase, a door, and a colored wall). Contrary to Hermer and Spelke (1994, 1996), they found that the children could combine geometric information and landmark information. Children went to the correct corner both when it was marked by a landmark (such as the door) and when it was unmarked (opposite the door).

What caused children of the same age to rely on allocentric representations in one study, and landmark-based representations in the other? The key to this puzzle turns out to be the size of the rooms. The studies showing that children did not rely on landmarks were conducted in very small rooms (4 × 6 feet), whereas the studies showing that children combined geometric and landmark information were conducted in much larger rooms (8 × 12 feet). In a direct comparison of children’s performance in rooms of different sizes, Learmonth, Nadel, and Newcombe (2002) found that, indeed, young children do not use landmarks in small rooms, but they do use them in larger rooms. One possible explanation for this finding is that rooms of different sizes demand different sorts of spatial thinking because they allow for different sets of possible actions. Unlike the smaller room, the larger room allowed plenty of space to move about, so it may have been more likely to engage thinking in service of locomotion.

More generally, this set of studies highlights that the type of spatial thinking people engage in depends crucially on the nature of the task and on features of the environment. Understanding how knowledge about space develops will require further research about how children at various points in development weigh different potential sources of spatial information in different settings (Newcombe & Huttenlocher, 2000).

**How is spatial knowledge acquired?** One obvious source of spatial information is action within the environment. Developmental changes in infants’ capabilities for action, such as the onset of crawling, allow them to obtain new information about the environment, and this information informs their spatial representations. As noted above, self-produced locomotion seems especially important in enabling children to override egocentric representations of space.

Other forms of perceptual experience also play a crucial role in refining spatial representations, as studies of visually impaired people have shown (Rieser, Hill, Talor, Bradfield, & Rosen, 1992). Rieser et al. contrasted the spatial representations of adults who developed severe visual impairments either early in life (almost always before birth) or later in life (usually after age 10). The task was to imagine standing at a particular landmark facing in a particular direction in a familiar part of one’s neighborhood and to point toward where other imagined landmarks would be. Those whose visual impairments began early in life and whose peripheral vision was impaired represented the spatial layout much less accurately than those whose impairments started later or whose peripheral vision was intact. The finding suggested that early perceptual learning is critical for the development of accurate spatial representations.

The centrality of spatial knowledge within one’s culture also influences the degree to which children develop spatial skills. Evidence for this came from a unique study of aborigines living in the western desert of Australia (Kearins, 1981). These aborigines have followed a nomadic hunting and gathering lifestyle for thousands of years. Their children do not attend formal schools. On most tests of cognitive functioning, the children do far less well than children of the same ages in Europe and North America.

Kearins reasoned, though, that a different picture might emerge if the focus was on types of thinking that were important in the aboriginal culture. Spatial thinking fit this criterion. Much of aboriginal life is spent trekking between widely spaced wells and creeks. Whether a particular location has water depends on capricious rainfall patterns. Few obvious landmarks exist in the stony desert to indicate the wells’ and creeks’ locations; thus, high-quality spatial thinking is important for survival.

This reasoning led Kearins to contrast the spatial memory of aboriginal children raised in the desert with those of Australian children raised in the city. An experimenter presented 20 objects arranged in a 5 × 4 rectangle. After 30 seconds, she picked up the objects and then asked children to rearrange them as they were before.

The aboriginal children’s memory for the spatial locations proved superior. They also differed from the urban children in their strategies for remembering. The aboriginal children studied in silence. When subsequently asked how they remembered where objects had been, they often said they remembered “the look
of it." In contrast, the city-dwelling children used verbal rehearsal; they could be heard whispering and saying aloud the names of the objects while they studied them. The urban children's strategy is effective for remembering verbal material of the types needed to do well in school, but the aboriginal children's strategy is more useful for remembering spatial information. Thus, each group relied on strategies that were useful for the tasks of greatest importance in their everyday lives.

**NUMBER**

Understanding of numbers involves two basic types of knowledge: understanding of cardinality and understanding of ordinality. Cardinality refers to absolute number size. A common property of people's arms, legs, eyes, and feet is that there are two of them. The cardinal property of "two-ness" is what these sets share. Ordinality refers to relational properties of numbers. That someone is the third-tallest girl in the class and that five is the fifth number of the counting string are ordinal properties.

**Understanding of cardinal properties.** Understanding of cardinality begins early in infancy. In their first half year, infants can discriminate one object from two and two objects from three (Antell & Keating, 1983; Starkey, Spelke & Gelman, 1990; van Loonbroek & Smitsman, 1990). This was learned through the use of the habituation paradigm. Infants were shown a sequence of pictures, each of which contained a small set of objects, such as three circles. The sets differed from trial to trial in size of the objects, brightness, distance apart, and other properties, but they always had the same number of objects. Once the infants habituated to displays with this number of objects, they were shown a set that was comparable in other ways to the displays they had seen but that had a different number of objects. Infants increased their looking time to the set with the novel numerosity, suggesting that they had abstracted the number of objects in the previous sets.

But do these findings indicate a true understanding of number, or might they be due to some other variable that is confounded with number, such as the length of the contour of the objects, or the visible surface area of the objects? In studies designed to tease apart these factors, it appears that infants do indeed respond based on contour length (Cleartfield & Mix, 1999) or visible surface area (Feigenson, Carey, & Spelke, 2002), rather than on number per se. However, several other studies with strict control conditions have shown that infants can discriminate quantities based on number alone (Wynn, Bloom, & Chiang, 2002; Xu & Spelke, 2000). Furthermore, infants' ability to discriminate among small quantities extends to sequences of events as well as static arrays of objects (Canfield & Smith, 1996; Starkey et al., 1990). For example, when 6-month-olds see a puppet repeatedly jump twice until they grow bored, and then see the puppet jump three times or one time, they show renewed interest, indicating that they discriminated among the number of jumps (Wynn, 1995). Thus, it appears that infants are capable of discriminating quantities based on number, as well as on continuous dimensions such as surface area and contour length. However, when continuous dimensions as well as number vary, infants often rely on the continuous dimensions.

Most studies of infants' discrimination of number have utilized numbers smaller than three. Infants are not able to discriminate among sets of objects with larger numerosities, unless the sets differ by a large ratio (such as 8 versus 16; Xu & Spelke, 2000). Not until 3 or 4 years of age are children able to discriminate four objects from 5 or 6 (Starkey & Cooper, 1988; Strauss & Curtis, 1984). These findings suggest that infants identify small cardinalities through subitizing, a quick and effortless perceptual process that people can apply only to sets of one to three or four objects. When we see a row of between one and four objects, we feel almost immediately what exactly there are, in contrast, with larger numbers of objects, we rarely know the exact number. Adults and 5-year-olds are similar to infants in being able to very rapidly identify the cardinal number of one to three or four objects, but not larger sets, through subitizing (Chi & Klahr, 1975).

Infants' nascent understandings of cardinality also make it possible for them to recognize the consequences of adding and subtracting small numbers of objects. Wynn (1992a) found evidence for this ability in 5-month-olds. As seen in Figure 8.5, infants saw a toy mouse on a stage, then saw a screen come up in front of them, then saw a hand place another toy mouse behind the screen, and then saw the screen drop. Sometimes the result was what would be expected by adding the one new object to the one that was already behind the screen; other times (through trickery) it was not. The infants looked for a longer time at unexpected outcomes (either one mouse or three mice) than at the expected outcome (two mice), suggesting that they expected that 1 + 1 = 2. Other infants saw a subtraction event, in which two mice were placed on stage and hidden by the screen, and then one mouse was removed from behind the screen. Again, infants looked longer at the unexpected outcome (two mice) than at the expected one (one mouse), suggesting that they expected that 2 - 1 = 1.

Based on these findings, Wynn (1992a) has argued that "infants are able to calculate the precise results of simple arithmetical operations" (p. 750). Can infants really perform arithmetic? Wynn's basic finding has been replicated several times (Simon, Fespos, & Rochat, 1995; Uller, Huntley-Fenner, Carey, & Klatt, 1999). However, some attempts to replicate it have not succeeded (Wakeley, Rivera, & Lang, 2000), suggesting that infants' calculation abilities are not very robust. Another caveat is that, as for cardinality, infants demonstrate understanding only when the "problems" involve very small numbers (three or fewer). Children do not understand the consequences of adding even slightly larger numbers, such as 2 + 2, until they are 4 or 5 years old (Huttenlocher, Jordan, & Levine, 1994; Starkey, 1992).
assign numbers to larger sets than can be subdivided. Gelman and Gallistel (1978) noted the rapidity with which children learn to count and hypothesized that the rapid learning was possible because it was guided by knowledge of counting principles. In particular, they hypothesized that young children know:

1. The one-one principle: Assign one and only one number word to each object.
2. The stable order principle: Always assign the numbers in the same order.
3. The cardinal principle: The last count indicates the number of objects in the set.
4. The order irrelevance principle: The order in which objects are counted is irrelevant.
5. The abstraction principle: The other principles apply to any set of objects.

Several types of evidence indicate that children understand all of these principles by age 5, and some of them by age 3 (Gelman & Gallistel, 1978). Even when children err in their counting, they show knowledge of the one-one principle, since they assign exactly one number word to most of the objects. For instance, they might count all but one object once, either skipping or counting twice the single miscounted object. These errors seem to be ones of execution rather than of misguided intent. Children demonstrate knowledge of the stable order principle by almost always saying the number words in a constant order. Usually this is the conventional order, but occasionally it is an idiosyncratic order such as “1, 3, 6” that a particular child uses consistently. The important phenomenon is that even when children use an idiosyncratic order, they use the same idiosyncratic order on each count. Preschoolers demonstrate knowledge of the cardinal principle by saying the last number with special emphasis and by responding with that number when asked how many objects there are in a set that they have counted. They show understanding of the abstraction principle by not hesitating to count sets that include different types of objects. Finally, the order irrelevance principle seems to be the most difficult, but even here, 5-year-olds demonstrate understanding. Many of them recognize that counting can start in the middle of a row of objects, as long as each object is eventually counted. Although few children can state the principles, their counting performance suggests that they know them.

Gelman and Gallistel (1978) argued that one reason the principles are important is that understanding of them guides children’s acquisition of counting skill. This argument rests on the assumption that children understand the principles before they count accurately. However, a variety of subsequent findings have indicated that children actually count skillfully before they understand the principles that underlie counting (Bermejo, 1996; Bieri & Siegler, 1984; Frye, Braisby, Lowe, Maroudas, & Nicholls, 1989; Wynn, 1992b). Experience with counting may provide a database from which children can distinguish essential features of the usual counting procedure (such as counting each object once and only once) from incidental ones (such as starting at the leftmost or rightmost end of a row).

**Ordinal properties of numbers.** Ordinality refers to the relative positions or magnitudes of numbers. A number may be first or second in an order, or it

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**Why might infants demonstrate arithmetic competence only with small numbers?** As noted above, one possible explanation is that infants determine the number of objects by subitizing (Haith & Benson, 1998). This process is effective with very small sets, but not for sets of four or more objects. The case illustrates an important general lesson. Understanding children’s thinking requires understanding the processes they are using to solve the problems. The findings with infants might lead to the conclusion that infants “understand” addition. This is true in a sense, but it leaves totally unclear why they can apply it only to sets of one to three objects. The idea that infants solve the small number problems with a process that cannot be applied to larger sets, and that the process that can be applied to larger sets (counting) develops considerably later, makes understandable both their competence and their incompetence.

**Counting.** At 3 or 4 years of age, children become proficient in another means of establishing the cardinal value of a set—counting. This allows them to
may be greater or less than another number. Mastery of ordinal properties of numbers, like mastery of cardinal properties, begins in infancy. However, it seems to begin later, at around 10 months.

The most basic ordinal concepts are more and less. To test whether infants understand these concepts as they apply to numbers, Feigenson, Carey, and Hauser (2002) had 10- and 12-month-olds watch an experimenter place different numbers of crackers sequentially into two different containers. The infants were then allowed to crawl to get the crackers from the container of their choice. In comparisons of one versus two and two versus three crackers, both 10- and 12- month-olds consistently chose the container with the greater number of crackers. However, both groups of infants chose randomly in comparisons that involved numbers greater than three, such as three versus four and two versus four. Thus, as for cardinality, infants’ knowledge of ordinality appears to be limited to very small numbers.

However, one recent study suggested that infants may understand ordinal relations that involve fairly large values, if the ratio between the values is high. Brannon (2002) used a habituation paradigm to examine infants’ ability to discriminate between increasing and decreasing sequences. In order to make this discrimination, infants must recognize that one sequence changes so that each successive set has more than the previous set, and the other sequence changes so that each successive set has less. Infants were habituated to either increasing sequences (such as 2, 4, 8, 16) or decreasing sequences (such as 8, 4, 2 and 16, 8, 4) until they lost interest. In both types of sets, the ratio between adjacent numerosities was always 1:2. Infants were then tested with a novel sequence that was either the same direction or the opposite direction as the sequences to which they had been habituated (for infants in the increasing group, either 3, 6, 12 or 12, 6, 3). Eleven-month-old infants, but not 9-month-old infants, showed renewed interest in the test set with the novel direction, indicating that they distinguished the increasing from the decreasing sequence.

As for cardinality, extending the early understandings of ordinality to larger sets and to values that are close together takes a substantial amount of time. By age 2, children perform better than chance at making ordinal judgments with pairs of values up to six, even on difficult pairs such as 4 versus 5 and 4 versus 6 (Brannon & Van de Walle, 2001). However, children do not display full-fledged competence with larger numbers until several years later.

The task most often used to examine understanding of ordinality in early childhood involves asking questions such as “Which is more, 6 oranges or 4 oranges?” Not until age 4 or 5 can children solve such problems consistently correctly for the numbers from one to nine (Siegel & Robinson, 1982). Their difficulty in determining the larger number is greatest with numbers that are relatively large and close together (such as 7 versus 8). Counting skills may be important in the development of this ordinal knowledge; the number that occurs later in the counting string is always the larger number, and it is easier to remember which number comes later when the numbers are farther apart.

In sum, it appears that infants have a rudimentary understanding of ordinality by the end of their first year. However, this understanding is fragile, and it is displayed only with small numbers, or in situations in which the ratio between values is large. An important task for future research in this area is to map out the developmental course of this knowledge, and to investigate how it relates to later understanding of ordinality that relies on knowledge of counting.

BIOLGICAL CONCEPTS

Like time, space, and number, biology has been considered a “foundational” domain in human cognition, because knowledge about biological phenomena is important for basic survival, as well as for getting along in everyday life (Wellman & Gelman, 1998). From this perspective, it is not surprising that human children seem to be fascinated with living things.

Biological knowledge involves several interrelated concepts. These include fundamental biological categories, such as living things, animals, and plants, and basic biological processes, such as growth, inheritance, and illness. Research on children’s biological understanding has focused on when children demonstrate understanding of biological categories and processes, and how children acquire such knowledge, and on the extent to which children’s knowledge about biology forms a coherent “theory” of the domain of biology.

Biological categories. When do children begin to distinguish between biological entities and other sorts of entities? The most basic biological distinction, and the earliest acquired, is the distinction between animate and inanimate objects (Gelman & Opfer, 2002; Rakison & Poulin-Dubois, 2001). Even before their first birthday, infants categorize birds as different from airplanes and animals as different from vehicles (Mandler & McDonough, 1993, 1998a). They also recognize that animals differ from other types of objects in being able to drink and to sleep (Mandler & McDonough, 1986, 1998b).

On what basis do infants begin to discriminate animate and inanimate objects? One possibility is the presence of certain features, such as having a face. As described in Chapter 5, faces are particularly compelling for human infants (Dannemuller & Stephens, 1988; M. H. Johnson & Morton, 1991). Within the face, the eyes may be especially important (S. C. Johnson, Slaughter, & Carey, 1998). An early bias to attend to eyes or faces could provide a basis for distinguishing animate from inanimate objects.

Another source of information that infants may use to discriminate animate and inanimate objects is motion. Early in their first year, infants discriminate between biological and nonbiological motion (e.g., Bertenthal, 1993), and they begin to associate different types of motion with animate and inanimate objects. For example, by 9 months, infants seem to expect that humans are capable of self-initiated motion, but inanimate objects are not. They demonstrate
increased negative affect when they see a robot move independently (via a remote-controlled device), but not when they see a human being do so (Poulin-Dubois, Lepage, & Ferland, 1996). Infants also seem to expect goal-directed movement from humans but not from inanimate objects. By 6 months, infants display different patterns of looking to events that involve a human arm reaching out to touch an object and events that involve a mechanical "arm" reaching out to touch the object (Woodward, 1998).

The distinction between living and nonliving things is much more difficult for children than the distinction between animate and inanimate objects, and it is acquired much later. Even elementary school children often make errors when asked which things are alive (Carey, 1985; Richards & Siegler, 1984). One especially difficult category for children is that of plants. Between the ages of 3 and 5, children demonstrate knowledge that, like animals, plants take in food and water (Inagaki & Hatano, 1996), grow (Hatano et al., 1993; Hickling & Gelman, 1995), heal after injuries (Backscheider, Shatz, & Gelman, 1993), and die (Nguyen & Gelman, 2002). Further, children recognize that, like animals, plants die due to illness or old age (Nguyen & Gelman, 2002), they decompose after death (Springer, Nguyen, & Samaniego, 1996), and they cannot return to life after they die (Nguyen & Gelman, 2002). However, for several years beyond preschool, children remain unsure whether plants should be grouped with animals as living things (Hatano et al., 1993; Richards & Siegler, 1984). Not until late elementary school do most children possess an integrated concept of living things that includes both animals and plants.

**Biological processes.** To be a uniquely biological process, a process must be viewed as depending not on psychological mechanisms (such as desire) or physical mechanisms (such as physical force), but on specifically biological mechanisms. For many uniquely biological processes, this understanding emerges in the early preschool years.

One of the most fundamental biological processes is self-generated movement. The work reviewed above indicates that children have a rudimentary understanding of biological motion in infancy. By the preschool years, children's knowledge about biological and nonbiological movement is well differentiated. Preschoolers make accurate predictions about what types of objects are capable of movement (Massey & Gelman, 1988), and they offer different sorts of explanations for biological and nonbiological movement. For example, preschoolers report that a hopping chinchilla moves "by itself," whereas a hopping wind-up toy moves because of human intervention (Gelman & Gottfried, 1986). Thus, children recognize that biological mechanisms that produce movement are distinct from physical ones.

Preschoolers also understand growth as a fundamental biological process. By age 3 or 4, children know that only living things grow; inanimate objects such as toys and furniture do not (Carey, 1985; Rosengren, Gelman, Kalish, & McCormick, 1991). Preschoolers also understand that biological growth is essentially unidirectional, with organisms growing from smaller to bigger but not the reverse. Similarly, they know that growth proceeds from simpler to more complex forms (from caterpillar to butterfly, or tadpole to frog) rather than the reverse (Rosengren et al, 1991). Preschoolers also realize that people cannot prevent a baby animal from growing, even if they "want to keep it forever in the same size because it's so small and cute" (Inagaki & Hatano, 1987). Thus, they recognize that growth depends on biological mechanisms and not on psychological processes such as desire.

**Inheritance** is another fundamental biological process for which understanding emerges in the preschool years. Of course, preschool children do not have knowledge about genetic transmission or DNA, but nevertheless they display a rudimentary understanding of inheritance. They know that baby animals grow into beings that resemble adults of their species, even if they do not look like them at birth, whereas the same will not happen with dolls or other inanimate objects (Gelman & Wellman, 1991). Children also realize that a baby animal will grow up to become an adult of its own kind, even if it is raised by parents of another species (Johnson & Solomon, 1996). Likewise, if an animal is raised in an environment that is more appropriate to another type of animal, children understand that the animal will still have characteristics appropriate to its own kind. For example, a cow raised among pigs will moo (not oink) and have a straight tail (not a curly one). Children also apply this understanding to seeds planted in a setting more appropriate for another type of plant, such as an apple seed planted in a pot of flowers (Gelman & Wellman, 1991; Peterson & Siegal, 1997).

Children's early conception of inheritance appears to involve specifically biological mechanisms. Springer and Keil (1991) asked children to rank-order a number of different possible mechanisms for how a flower, a dog, and a metal can acquire their colors. For the flower and the dog, children preferred natural mechanisms, including both natural internal mechanisms (such as "the baby flower turned pink because its mom gave it something while it was growing inside the seed that made it pink") and natural external mechanisms (such as "the sun and rain fell on it while it was growing inside the seed and made it pink"). In contrast, for the can, children preferred a mechanical explanation that involved a human agent (such as "the worker who made the can did something that made it turn green").

However, despite this evidence for early understanding, preschoolers' conception of inheritance remains limited for several years. For example, preschoolers believe that mothers' desires may play a role in their children's inheritance of physical traits (Weissman & Kalish, 1999). Thus, it appears that preschoolers believe that there are psychological as well as biological mechanisms that underlie inheritance. It is not until about age 7 that children understand the importance of biological parenthood and birth in accounting for physical resemblance between parents and offspring (Solomon, Johnson, Zaitchik, & Carey, 1996).

Preschool children also understand illness as a fundamental biological process. Four- and 5-year-olds realize that illness can be caused by an invisible
mechanism, namely, the action of germs (Kalish, 1996). Based on knowledge of germs, preschoolers predict that risky actions, such as eating food from the garbage, will not cause illness if germs are not present, and innocuous actions, such as eating food that had fallen in water, will cause illness if germs are present. Furthermore, preschoolers distinguish the causes of illness from the causes of psychological reactions, such as sadness (Kalish, 1997). They realize that physical contact with a contaminant will lead to illness, even if the affected individual has no knowledge of the contaminant. However, emotional reaction to a contaminant (such as beliefs that something is disgusting or "yucky") depend on knowledge of the contaminant. Thus, they differentiate a biological reaction to a contaminant (illness) from an emotional reaction to the same contaminant (disgust).

Despite their early understanding of the mechanisms that cause illness, preschoolers' knowledge about illness remains limited. Most preschoolers do not understand how that illness takes time to develop; instead, they tend to see instantaneous response to contamination (Kalish, 1997). Further, they tend to view the outcomes of causes of illness in an all-or-none fashion (Kalish, 1998b). For example, if all of the children in a particular classroom played with a sick child, preschoolers tend to predict that either all or none of the children would get sick. Thus, children fail to recognize that causes of illness operate in a probabilistic fashion.

In sum, although their knowledge is limited in important ways, preschool children do understand basic aspects of several fundamental biological processes, including movement, growth, inheritance, and illness. Furthermore, in most cases, preschoolers distinguish biological mechanisms from psychological and physical ones. Thus, by preschool, children have knowledge about causal mechanisms that are uniquely biological.

**How do children acquire knowledge of biology?** From a developmental perspective, it is important to understand not only the nature of children's biological knowledge, but also how such knowledge is acquired. A number of alternative accounts of how children acquire biological concepts have been proposed. Some researchers have claimed that humans have innately specified brain structures or processes that foster their learning of biological concepts. For example, Atran (1994) has argued that humans are born with a "biology module," which developed over evolutionary time, that fosters early and rapid learning of biological things. One key form of evidence for this view is cross-cultural similarities in the nature and content of children's biological knowledge (Lopez, Atran, Coley, Medin, & Smith, 1997).

Other researchers have focused on the roles of experience and environmental input in children's acquisition of biological knowledge (e.g., Callanan, 1990; Springer, 1995, 1999). For example, Inagaki (1990) found that 5-year-old children who had raised goldfish as pets at home were better able than children who had not raised goldfish to make predictions about the behavior of an unfamiliar animal (a frog). Thus, the experience of caring for a pet helped children to acquire biological knowledge that they could generalize to another species. Children also acquire biological knowledge in everyday interactions with parents and other caregivers. Gelman and colleagues (Gelman, Coley, Rosengren, Hartman, & Pappas, 1998) observed mothers as they read picture books about animals with their 1- and 2-year-old children. They found that mothers' statements and gestures often emphasized the taxonomic relations among different types of animals and sometimes described or pointed out characteristics of different categories of animals or of animals in general. Such implicit teaching may contribute to children's developing biological knowledge.

Explicit teaching also contributes to the development of children's biological knowledge. Solomon and Johnson (2000) investigated the role of explicit instruction in 5- and 6-year-olds' understanding of biological inheritance. They taught children a key fact ("babies come from their mothers' bellies") and they also provided them with some rudimentary information about genes ("tiny things called genes inside of us make us what we are"). "rabbits with brown fur have brown fur genes and rabbits with white fur have white fur genes"). Children who received instruction not only learned the taught concepts, but they also reorganized their knowledge about inheritance to highlight the importance of birth in mediating physical resemblance, but not similarities in beliefs, between parents and offspring. Thus, instruction provoked substantial change in children's conceptions of inheritance.

Of course, both nature and nurture play important roles in children's acquisition of biological concepts. Young children all over the world are fascinated with animals and plants, and they are highly motivated to learn about them. The social and cultural context in which children develop provides them with many opportunities for learning about living things. In some cultures, at least part of this learning takes place within formal instruction. However, children also learn about biology through their own direct experiences of nature, through interacting with pets, farm animals, and houseplants, and through conversations, stories, and television programs.

**Does children's knowledge form a coherent "theory" of biology?** Based on the compelling evidence for knowledge of biological categories and processes in preschool, some researchers have argued that children possess a naïve "theory" of biology even before they receive formal schooling (Hatano & Inagaki, 1994; Karmiloff-Smith, 1992). What characteristics must children's knowledge have in order to be considered a "theory"?

Wellman and Gelman (1992, 1998) proposed four criteria that characterize theoretical understandings: fundamental categories unique to the domain, causal explanations unique to the domain, unobservable explanatory constructs, and coherent organization. As described above, from a very early age, children's biological knowledge incorporates knowledge about fundamental categories such as animate objects, living things, animals, and plants. By preschool, children
understand that the actions of biological entities reflect causal processes that are unique to the domain of biology, such as growth, inheritance, and illness. They also understand that some of these processes are mediated by unobservable explanatory constructs that are unique to the domain of biology, such as germs. Finally, learning new information sometimes leads children to reorganize their biological knowledge; thus, it appears that this knowledge has a coherent structure. Taken together, these findings suggest that preschoolers' understanding of biology constitutes a true theory, at least according to these criteria.

**Summary**

Conceptual development can be approached either by considering conceptual representations in general or by focusing on particular concepts of special importance. Conceptual representations in general can assume at least three forms: Defining-features representations depict concepts in terms of a few necessary and sufficient features. Probabilistic representations include many features that are associated with the concept to varying degrees, but no feature that is necessary and sufficient for category membership. Theory-based representations focus on causal relations among different aspects of conceptual understanding.

A number of prominent developmental theorists, including Piaget, Vygotsky, Werner, and Bruner, have formulated versions of the representational development hypothesis. According to this hypothesis, young children cannot form representations based on defining features. However, even 1-year-olds have proved capable of relying on such features with familiar concepts. Young children do appear to rely on defining-features representations less often than do older individuals, but they clearly can form them.

Both children's and adults' representations often emphasize probabilistic relations rather than defining features. Beginning in infancy, children abstract prototypical forms, detect cue validities, note correlations among features, and generate basic-level categories. Within a relatively short time, children also begin to form subordinate and superordinate concepts, move from child-basic to standard-basic concepts, and abstract increasingly complex correlational patterns.

Theory-based representations emphasize the role of causal and hierarchical relations. Many of children's concepts seem to have theoretical aspects that facilitate inferences, explanations, and generalizations, and help children overcome the influence of superficial perceptual similarity. There may also be certain core theories, such as theories of biology and of the mind, that have different qualities than concepts in general; the ways in which such theories differ from others, however, are not yet clear. Some concepts have theoretical aspects from early in life, but the depth and scope of theory-based concepts clearly increase greatly with development.

Another perspective on conceptual development is provided by focusing on the particulars of the development of concepts of special importance. Among these central concepts are time, space, number, and living things. These concepts are worthy of unusual attention because they are used to represent a vast range of experiences, because they are present in some form from infancy to old age in all of the world's cultures, and because understanding the world would be impossible without them.

Time has both experiential and logical aspects. Infants as young as 3 months encode the order in which events occur, thus showing a sense of experiential time. By age 5 years, they also can estimate reasonably well the durations of relatively brief events. By the same age, children have some knowledge of the logical relations among beginning, ending, and total time, though their grasp is tenuous and can easily be disrupted by misleading cues.

Locations and distances within space can be represented in terms of relations to oneself, in terms of relations to landmarks, or in terms of an abstract system. Egocentric representations lead infants younger than 1 year to continue turning in the direction that previously led to a goal, even when their position relative to the goal changes. Self-produced locomotion, in particular crawling and walking, appears critical to infants overcoming the tendency to represent space egocentrically. Landmarks close to objects help infants locate objects in space even during their first year. Similarly, even in the first year, infants can form allocentric representations, in which they represent space in terms of the entire spatial layout. Early experience correlating the flow of visual information with one's own movements may be critical for forming such allocentric representations of space.

Understanding of numbers involves understanding both cardinal and ordinal concepts. Children understand certain cardinal and ordinal properties of numbers in infancy. This is evident in their habituating to sets with a given number of objects and in their ability to choose the set with the larger number of objects. By the end of the preschool period, children supplement their early understanding of cardinality with understanding of counting and number conservation. They also supplement their understanding of ordinality with knowledge of numerical magnitudes.

Children's biological knowledge involves both fundamental biological categories, such as plants, animals, and living things, and uniquely biological processes, such as growth, inheritance, and illness. The earliest acquired biological distinction is that between animate and inanimate objects. Over time, children's knowledge about biological categories becomes more differentiated, with understanding of plants as living things being a relatively late achievement. For many uniquely biological processes, understanding emerges in the early preschool years. However, preschoolers' knowledge of biological processes is relatively limited, and it continues to be enriched throughout childhood. Nevertheless, preschoolers' knowledge of biology has several
hallmarks of theoretical understanding, including fundamental categories unique to the domain, causal explanations unique to the domain, unobservable explanatory constructs, and coherent organization. Thus, children appear to have a theory of biology starting in the preschool years.

Recommended Readings


Rieker, J.I., Garing, A.E., & Young, M.F. (1994). Imagery, action, and young children's spatial orientation: It's not being there that counts, it's what one has in mind. Child Development, 65, 1262-1278. Action, perception, and imagery are linked in complex and surprising ways. This study demonstrates that walking through one space improves children's representations of other spaces, if children are thinking about those other spaces while they are walking.


The Development of Social Cognition

JEREMY (AGE THREE): Mommy, go out of the kitchen.
MOTHER: Why, Jeremy?
JEREMY: Because I want to take a cookie. (from Peskin, 1992)

The child in the vignette above wanted to deceive his mother but was not quite able to pull it off. He seemed not to realize that telling his mother about his planned misbehavior would probably have the same outcome as her seeing it. Conversations such as this one reveal that young children's understanding of other people is profoundly different from that of adults. This chapter focuses on children's cognition about the social world—their understanding of themselves and other people, of how the human mind works, and of social rules and social categories.

Children develop in a world filled with other people. As emphasized by sociocultural theories (Chapter 4), social relationships have a profound effect on what children do, on what they think about, and on how they think. Furthermore, social relationships are essential for healthy development and for optimal functioning throughout life. Given these facts, the importance of understanding children's thinking about other people and about the social world seems clear.