

Changing Views of Cognitive Competence in the Young

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It was once commonly thought that the newborn child cannot hear, see, or smell; that the first year of life is spent in a blooming-buzzing confusion; and that infants lack ability to form complex ideas about the world. For much of this century, most experimental and developmental psychologists accepted the traditional thesis that the newborn's mind is a blank slate (or *tabula rasa*) upon which the record of experience is gradually impressed. It was further held that language is an obvious prerequisite for any abstract thought (e.g., Vygotsky, 1962; Whorf, 1956), so in its absence, a baby could not have knowledge of anything other than sensations. Since babies are born with an extremely limited repertoire of behavior and spend most of their early months asleep, they certainly appear passive and unknowing; there is no obvious way for them to demonstrate otherwise.

But challenges to this view arose. On the theoretical side, it is hard to overestimate the impact of Piaget, Chomsky, Simon, and the Gibsons, who profoundly influenced psychologists' ideas of what to look for and how to characterize the child. These new theoretical views stimulated innovative research programs with the very young. It became clear that with carefully

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designed methods one could find ways to pose rather complex questions to infants and young children. A substantial new body of data has now accumulated about the capacities of infants and young children and stands in contrast to the older emphasis on what they lack. From these data a contemporary view has emerged that the very young can be competent, active agents of their own conceptual development. In short, the mind of the young child has come to life.

This essay is divided into four parts. First, we introduce the seminal theoretical ideas that have influenced psychologists' conceptions of the child's emergent mind. Next, we delineate some of the evidence in support of infant and preschool cognitive competence and illustrate some of the methods developed to make the study of young minds plausible. Finally, we ask how this putative youthful brilliance interacts with formal learning tasks in school, emerging with a seeming paradox: Young children seem to know more than we thought possible, but older children in schools seem to be much less competent than was once assumed. The natural learning settings of young children are contrasted with the formal environments they encounter at school, and we see that instructional programs that capitalize on young children's natural propensities to create and test theories can significantly accelerate learning.

THEORETICAL BACKGROUND

The first step away from the empiricists' "tabula rasa" view of the infant mind was taken by the Swiss psychologist Jean Piaget. Beginning in the 1920s, Piaget argued for the need to postulate complex cognitive structures in the young human mind, which empiricist accounts of human thought had tended to play down or deny. Piaget did not think that human infants are born with innate cognitive structures, but rather that structures develop due to the child's ever-present tendency to engage the environment actively, interpreting it in accordance with progressively changing cognitive "schemes." From close observations of infants and careful questioning of children, he concluded that cognitive development proceeds through certain stages, each involving radically different cognitive schemes, so that sometimes young children even form practical convictions contrary to those held by older children and adults.

While Piaget observed that infants actually seek environmental stimulation that promotes their intellectual development, he thought that their initial representations of objects, space, time, cause, and self are constructed only gradually during the first two years. He concluded that the world of young infants is an egocentric fusion of the internal and external worlds, and that the development of an accurate representation of physical reality

depends on the gradual coordination of schemes of looking, listening, and touching. Piaget thought that for many months the infant does not realize that an object producing a given sound is the same as an object that looks a certain way. The very young infant, up to 10 months or so, was said to think that an object exists only as long as she can touch, hear, or see it; once out of direct sensory contact, it ceased to exist. From this view, it followed that babies do not represent an independent space in which three-dimensional objects exist. In this regard, Piaget's account of infant cognition is actually close to being empiricist; still the position that cognitive schemes are actively constructed rather than passively impressed separates him from empiricists (or in modern terminology, behaviorists).

Noam Chomsky (1957), focusing on language, proposed that the human mind is innately prepared to learn language without needing much help from the environment. He provided explicit hypotheses about the nature of the language structures that produce and comprehend language, an account that held out the promise of explaining how young children can say things they have never heard, e.g., "I'm unthirsty." "I have two footses," "I went home." Chomsky's hypotheses are still controversial (Wanner and Gleitman, 1982), but the effect of his work gave strong impetus to a "nativist" account of mental abilities, which maintains that humans are born with conceptual structures that guide the acquisition of knowledge about the world.

Like Piaget, the Gibsons have maintained that infants actively explore the environment, but in sharp contrast, they deny that the infant slowly constructs the world. They maintain that, shortly after birth, the infant's world is a remarkably veridical one, filled with three-dimensional objects in real space, not unconnected elementary sensations. They support their view with findings that neonates integrate sight and sound and respond as if they assume that the world is out there waiting to be explored. The Gibsons assign a role to learning but propose that it proceeds rapidly due to the initial availability of exploration patterns that can yield accurate information about objects and events.

Simon (1972) and his colleagues (e.g., Klahr and Wallace, 1976) helped introduce a somewhat different perspective, that development means overcoming information-processing constraints, such as limited short-term memory capacity and lack of general knowledge. Those working in the information-processing tradition focused both on the possibility that early failures in completing Piagetian tasks are due in part to limits on processing capacity and the conditions under which children actively employ strategies for problem solving and knowledge acquisition.

All these theoretical developments challenged the empiricist account and influenced the direction of research in developmental psychology. The claim

that young children have different mental structures and ideas about the world was taken up in investigations of their concepts, strategies, and problem-solving abilities. These studies led to the conclusion that, despite the many differences between young and old, the young have remarkable abilities to participate actively in their acquisition of knowledge.

STUDYING INFANT KNOWLEDGE

Because infants are so limited physically, experiments to find out what they know and how they think have had to find methods suitable to the level of infant motor capabilities. A good example is a method used by Kalnins and Bruner (1973). They showed 5- to 12-week-old infants a silent color film and gave the infants a pacifier to suck, the nipple of which was connected to a pressure switch controlling the projector lens. The infants quickly learned to suck at a given rate to bring the movie into focus, showing not only that they were capable of and interested in learning how to control their own sensory environment but also that they preferred a clear image to a blurry one.

A second method demonstrates—and depends on—an infant's thirst for novelty. The "habituation paradigm" involves presenting babies with a stimulus—a picture, sound, or series of sounds—to which the baby attends either by looking at it, turning to it, or doing something to keep the stimulus on. Over a series of trials, infants, like everyone else, stop responding to repeated presentations of the same stimulus; that is, they *habituate*. They recover interest if a recognizably different stimulus is presented. For example, four-month-old infants will suck vigorously when first introduced to the phoneme (speech sound) "ba," then gradually lose interest and stop sucking in response to it. But when presented a different phoneme, "pa," they resume sucking (Eimas et al., 1971).

Fantz (1961, 1966) directed attention to the power of the preference method to study infants' tendency to explore. He determined what infants looked at by watching their eyes closely. Infants lying on their backs in his laboratory could look up to the left or right at, for example, a bull's eye and a checkerboard. The experimenter recorded whether and for how long the baby looked left or right. Even newborns chose to look at patterned displays over homogenous gray ones. Infants generally prefer somewhat novel displays over ones they have seen before (e.g., Kagan et al., 1978; Kessen et al., 1972).

Studies like these do more than simply show that infants actively select experiences; they can also tell us what the infant is capable of perceiving and knowing. Recovery of interest in a novel speech sound could not occur if infants could not recognize the rather subtle difference between "pa"

and "ba." (See Aslin et al., 1983.) The same holds for visual preferences. Discovering that very young infants can see, hear, smell, and be particular about what exactly they perceive led to an emboldened attitude about the kinds of experimental questions that could be asked. The answers about infant understanding of the physical and numerical properties of objects have been quite remarkable.

Early Knowledge of Objects

Piaget concluded that before infants could know about objects they would have to discover regularities between their sensations and actions, then gradually integrate the sense-action schemes formed when they touched, heard, and looked at objects, and finally come to appreciate the object as a separate reality in the external world. Like the empiricists, Piaget thought infants responded to the immediate stimuli, i.e., flashes of light on the retina or sound waves in the eardrum, long before they recognized sources of stimuli.

Recent experiments (Gibson and Spelke, 1983; Harris, 1983) have told a different story. For example, Spelke (1976) used visual-preference methods to determine that four-month-old infants already integrate the sight and sound of an event. Infants were shown two films projected side by side—a person playing peek-a-boo and a hand beating a tambourine. The sound accompaniment of one film was fed to a hidden loudspeaker placed midway between the films. The babies reliably preferred to look at the movie corresponding to the sound source. Other research indicates that babies are born with a tendency to turn to a sound and visually search for something there (Field et al., 1980; Mendelson and Haith, 1976; Wertheimer, 1961).

This integrative capacity extends beyond auditory and visual properties to include the sense of touch. In recent experiments, Gibson and Walker (1984) gave one-month-old infants either a hard lucite cylinder or a lookalike soft sponge cylinder to explore with their mouths. The experimenter then showed each infant both cylinders, squeezing the spongy cylinder in one hand and rotating the hard cylinder with the other hand. The infants preferred to look at whichever cylinder had not previously been explored orally, showing a capacity to integrate what they saw with what they had mouthed. Meltzoff and Borton (1979) reported similar findings with objects that were smooth or had tiny nubs on their surface.

These findings establish two important points about the cognitive structure that infants employ to interpret sensory input from objects: (a) They endow objects with properties, such as rigidity, that transcend sensory modality; and (b) infants can appreciate such properties even when they are not acting on the objects.

Von Hofsten (1980) provides further evidence that babies know things about objects before they can successfully act on them. Around four months of age, infants are able to reach out and grasp objects. At the same time, without having had the experience of successfully catching a moving object, they also anticipate trajectories correctly and move their hand toward the spot where a moving object will be. This would appear to require reckoning of the velocity and direction of the object, foreknowledge of the time that the arm movement will take, and ability to combine these in calculating an intercept.

Piaget noted the considerable difficulty infants have with occluded objects. When infants four to eight months old are shown an interesting object, they reach for and grasp it and even follow its fall to the floor. But they stop reaching or looking if the object disappears behind a barrier. Infants 8 to 12 months old will seek and retrieve an object they see someone cover, but they show an odd tendency referred to as the "A not B error": If the baby sees an object taken from behind one barrier, A, and, while the baby watches, moved behind another barrier, B, the baby searches only behind the first barrier (A). Piaget concluded that "the object is still not the same to the child as it is to us: a substantial body, individualized and displaced in space without depending on the action context in which it was inserted" (Piaget, 1954:64). Recent research suggests that the A not B error may be confined to particular experimental situations (Bjork and Cummings, 1984; Sophian, 1984). After all, if babies can match what they mouth with what they see, distinguishing between solid and spongy substances, they must be sensitive to objects as substantial bodies.

As further evidence for this view, Bailargeon et al. (in press) showed five-month-old infants a screen that rotated toward and away from them through an arc of 180 degrees. Once the babies were habituated to the rotating screen, a yellow cube was placed alongside the screen for two trials of viewing. Then the cube was placed behind the screen; on alternating trials, the infant saw either a screen that once again rotated through the full 180-degree arc (and at least from the adult perspective seemed to crush the covered object) or a screen that rotated through only a 120-degree arc, stopping at the angle at which its further rotation would be blocked by the presence of a solid object behind the screen. (One-way mirrors and varied lighting accomplished the visual effects.) Although the infants had previously habituated to the full rather than partial rotation, they nonetheless looked longer at the full rotation, treating the habituated event as even more novel than one they had never seen before. These results suggest the babies expect solid objects to persist even when no longer in sight.

In short, considerable research with young infants has shown that they treat objects and events as sources for multiple kinds of sensory input, and

that they recognize in objects properties such as rigidity and solidity that transcend specific sensory modalities.

Abstract Concepts

Many theories of cognition have assumed that language is necessary to abstract properties common to a set of objects. Premack (1976) tellingly refuted this thesis when he showed that once a chimpanzee had learned the symbol for apple, it could apply that symbol to various parts of an apple (seed, peel, etc.). Preverbal human infants also recognize properties common to sets of nonidentical objects. Ross (1980), for example, habituated one- and two-year-olds to one of five classes of items: O shapes, M shapes, furniture, men, and food. Then children were shown another item from the same class or an item from a novel class. They preferred the item from the novel class. The children's ability to recognize category membership was uncorrelated with their ability to supply a verbal label for the category.

Number is a property of sets divorced from any description of the objects themselves. Hence, it is often treated as the ultimate in abstraction. A variety of results indicate that infants abstract number from visual displays of two, three, and sometimes four items (Starkey and Cooper, 1980; Starkey et al., in press; Strauss and Curtis, 1981). For example, six- to nine-month-old infants became habituated to color photographs of either two or three assorted common household items, e.g., sponge, cloth, vase, comb, apple, etc. (each trial displayed different items). Infants who were habituated to two-object displays then looked longer at three-item ones, and vice versa. Infants even abstract number intermodally (Starkey et al., 1983). They prefer to look at the one of two displays that matches the number of drumbeats (two or three) they hear emanating from a centrally placed loud-speaker.

Summary

We have sampled the evidence that infants are not passive, unstructured receivers of environmental input. Soon after birth they reveal an impressive degree of implicit conceptual structure allied to active learning endeavors. They behave as if they recognize that objects are independent of themselves, having size and solidity, and are specified intermodally. They reveal sensitivity to some properties of moving objects and form concepts about some abstract properties of sets. It is not at all obvious why infants bother to attend to the number of items they see or hear. But it looks as if human infants come prepared to learn quickly about objects and certain concepts, including number. These early competences provide a base from which

much natural learning proceeds during the preschool years. Acquisition of knowledge in these natural domains is guided as much by the availability of implicit structures and principles that guide the child's active learning about the nature of objects and events, causes, number, etc. as by the availability of a supportive environment.

PRESCHOOL THOUGHT

Principles About Numbers, Causes, and Objects

Preschool thought and its development are much influenced by implicit knowledge of fundamental principles governing the determination and manipulation of numbers, the character of physical causality, and the differences between animate and inanimate objects.

Number Many preschoolers spontaneously count collections soon after they learn to talk. Gelman and Gallistel (1978) propose that even these very young children make implicit use of some, if not all, of five principles of counting: (1) The tags used in counting must be placed in one-to-one correspondence with the items counted; (2) the tags must be drawn in order from a stably ordered list; (3) the last tag used represents the number in the set (cardinality); (4) the order in which the items are tagged is irrelevant; and (5) sets of arbitrary composition may be counted. What evidence is there for this view?

First, counting behaviors in young children are systematic, even when they use nonstandard tags or orderings. For example, Gelman and Gallistel (1978) report a two-and-one-half year old who said "one, two" when counting a two-item array and "one, two, six" when counting a three-item array (the one-one principle). The same child used her own list over and over again (stable order principle) and repeated her last tag when asked how many items she had (the cardinality principle). Such nonstandard lists in counting are like the systematic errors made by young language learners (e.g., "I runned"); just as the occurrence of such language errors implies use of language rules by the very young, so the occurrence of stable nonstandard lists can be taken as evidence of implicit counting principles. Further evidence for implicit counting principles is found in the fact that young children spontaneously self-correct their own and others' counting errors (Gelman and Meck, 1983) and often are inclined to count without any request to do so. Such behaviors point to a representation that monitors and motivates performance (Greeno et al., 1984).

Other studies have shown that preschool children solve simple arithmetic problems by using counting strategies they invent (Green and Resnick,

1977; Siegler and Robinson, 1982). To illustrate, Green and Resnick (1977) taught four- and five-year-old children to solve addition problems of the form $x + y = ?$ by counting out x blocks, counting out y more blocks and then counting the combined set. Children who practiced their addition over several weeks got better. More surprising is that over half of them invented a better way of solving the problems; counting on from whichever was the larger of the two values in the problem. To account for such inventions, it is necessary to postulate the use of something like an implicit principle of commutativity.

Finally, the preschool child also understands that addition and subtraction, unlike displacement, rearrangement, or item substitution, alter numerosity. This has been shown in "magic" experiments where a child is confronted with unexpected alterations in the sets used in a kind of shell game (Gelman, 1977). In these experiments children between the ages of three and five first learn to find plates holding different numbers of objects, e.g., two and three, underneath each of two cans. Then they discover surreptitious changes in the number, type, or arrangement of items in one array. Those children who encountered irrelevant changes deemed them such and those who encountered the effects of relevant transformations pronounced them relevant. For example, changes in number elicited considerable surprise, e.g., "Eecccc, how did that happen?" Further, the children postulated the relevant transformation, e.g., "One gone—Jesus Christ came and took it." They also could indicate what number they expected, what number they actually encountered, and what arithmetic operation would have to be performed to "fix" the game—in this case, addition.

Hence we see early implicit understanding of number, addition, and subtraction. We will later ask why this competence does not guarantee easy learning of mathematics in school.

Causality The suggestion that young children work with implicit notions of cause will surprise those familiar with Piaget's work on the development of the child's conception of causality. In one set of inquiries, Piaget asked children to explain a variety of natural and mechanical phenomena, e.g., the cycle of the moon, floating objects, the movement of clouds, the operation of steam engines, and bicycles, etc. Analysis of the explanations led Piaget to characterize the young child's thought as fundamentally *pre-causal*. He wrote, "Immediacy of relations and absence of intermediaries . . . are the two outstanding features of causality around the age of four-five" (Piaget, 1980:268).

Piaget's conclusion that a concern for mechanism is completely lacking in the preschooler is contradicted by several later lines of experimental

research. For example, Shultz (1982) showed two-year-olds the cause-effect sequence of turning on a blower that then blew out a candle. He then showed them two blowers, each surrounded on three sides by a plexiglass shield, the critical difference being whether the open side was facing the candle. If considerations of mechanism did not influence young children, they would choose randomly between the two blowers as potential causes of extinguishing the candle. Instead they systematically chose the unblocked blower. Similar findings were reported for the transmission of sound from a tuning fork or light from a battery. Preschoolers consistently took note of barriers that would stop the transmission of prerequisite energy. Comparable results were obtained by Shultz with schooled and unschooled Mali children in West Africa.

Other lines of evidence support the conclusion that preschoolers on many occasions do reveal an implicit concern for cause. Hood and Bloom (1979) note a ubiquitous tendency for children to seek causal accounts of what happens and how things work. Bullock (in press) showed that young children distinguish plausible from implausible mechanisms. At the start of her experiment, a rolling steel ball and a rolling light (produced as is the moving light effect in a movie marquee) moved simultaneously down parallel runways and disappeared together at the same time into an adjoining box. After a brief delay Snoopy jumped out of the box. Children were asked to identify the cause of Snoopy's jumping. They reliably named the ball. Since both preceding events were coterminous and redundant, the children should have shown no preference for one event over the other if they considered only temporal and spatial contiguity when reasoning about causality. Their preference for the ball (an object with momentum and kinetic energy) can be taken as evidence that they were concerned with plausibility of mechanism.

Findings like these have led many (e.g., Bullock et al., 1982; Koslowski et al., 1981; Shultz, 1982) to a view that preschool children work with a set of implicit assumptions about physical causality, including the crucial one that mechanisms mediate cause and effect relations. Guided by these implicit assumptions, they learn rapidly about their world; but, as we shall see, this does not guarantee the acquisition of scientifically correct theories.

Objects An early concern for mechanism may explain why preschool children are able to separate animate and inanimate objects (Carey, 1985a; Gelman et al., 1983; Keil, 1979). For example, three- to five-year-olds, asked whether a rock, a doll, and a person could walk, typically answered that a rock cannot walk because it has no feet; that a doll cannot walk unless someone pushes it, because its feet are only pretend; and that people can walk by themselves. In other words, inanimate objects cannot cause them-

selves to move, whereas animate ones can. Even infants treat animate and inanimate objects as belonging to different categories; they become very upset when a human stands still and fails to respond to them (e.g., Field, 1978; Tronick et al., 1975) but do not do so in the presence of inanimate objects. These findings have led theorists to postulate that humans are disposed to treat animate and inanimate objects separately at birth. Since infants respond differently to moving malleable objects than moving solid objects, this may reflect early recognition of fundamental differences in the way animate and inanimate objects move.

Making Plans and Strategies

This review of preschoolers' knowledge of numbers, causes, and objects only scratches the surface of evidence that the young are more competent than we once presumed. For example, there is compelling evidence that preschoolers' interest in and recall of stories reflects the availability of story grammars (Mandler, 1983; Stein and Trabasso, 1982); that preschoolers can systematically classify (Rosch et al., 1976); that they can be logical (Braine and Rumain, 1983); that they represent knowledge with a variety of coherent structures (Keil, 1981; Markman, 1981; Nelson and Gruendel, 1981); that children this age can take account of the perspective of an observer other than themselves (Lempers et al., 1977; Shatz, 1978); and even that congenitally blind children have Euclidean representations of space (Landau et al., 1981).

Given all this evidence, it should not be surprising to discover that preschool children are often strategic and playful when acquiring knowledge structures. This was not always assumed, however. The dominant developmental theories of the 1960s argued that a major shift in the quality of children's learning occurred between the ages of five and seven years; prior to that shift, children's learning was seen as primarily nonstrategic, passive, and context dependent; only after the shift was children's learning thought to become increasingly strategic, active, and flexible.

These ideas were not advanced in the abstract. An enormous empirical base backed them up (Stevenson, 1970; White, 1965, 1970), but much of this data base was built using experimental designs that were not suitable for young children. Given cognitive exercises designed for school-age students, preschoolers typically performed abysmally, if at all, thus confirming theoretical claims of their incompetence.

Systematic attempts to find more suitable ways to test the competence of younger children began in the 1970s (for a discussion see Brown and Deloache, 1978; Donaldson, 1978; Gelman, 1978). We will present some selections from the growing evidence that preschool children behave stra-

legically, often direct their own learning, and actively create, test, and refine their own theories of the world around them. Driving this reassessment of preschool learning has been a greater consideration of the context in which it is observed.

Strategies for Remembering A great deal of research in the 1960s and early 1970s was concerned with the development of school-age children's strategies for enhancing memory (Brown, 1975; Flavell, 1970a, 1970b; Kail and Hagen, 1977). A central theme was that preschool children would differ from grade-school children on tasks that demand a great deal of strategic ingenuity. Young children, failing to devise strategic plans, would be at a considerable disadvantage on tests of deliberate memory, whereas older children would display increasing competence, primarily because they deploy more and more effective learning strategies. But laboratory and school tests of deliberate memory do not translate readily into the contexts in which young children naturally practice their emergent retention skills. That four-year-olds tend to be at a loss when asked to reproduce lists of digits or letters does not mean that they completely lack the ability to plan for future memory demands.

How, for example, could one reconcile the diagnosis of nonstrategic learning with the following description of three-year-olds anticipating a memory test? Surreptitiously observing children as they attempted to remember which of several containers concealed a toy dog, Wellman et al. (1975) found clear evidence of rehearsal (looking at the target container and nodding yes, looking at the nontarget containers and nodding no), retrieval cueing (resting their hands on the correct container or moving it to a salient position), and focused attention (looking fixedly at the correct hiding place). The children refused to be distracted until they were permitted to retrieve the lost dog. These efforts were rewarded: children who prepared actively for retrieval did remember better.

DeLoache et al. (1985) found even earlier evidence of planning for future retrieval. Children 18 to 24 months old were observed playing a hide-and-seek game; an attractive toy (Big Bird) was hidden in a variety of locations in a laboratory waiting room, such as behind a pillow on a couch. A timer was set to indicate the retrieval interval of, for example, five minutes; when the bell rang, the child could retrieve the toy. Far from waiting passively, the children interrupted their play to engage in activities indicating they were still preoccupied with the memory task: talking about the toy, pointing to the hiding place, or attempting an illegal peek. The children did not engage in these "keep-alive" activities if the toy remained partially visible during the retention interval or if the experimenter was responsible for remembering the location. Many other examples of early strategic com-

petence could be cited; precocious strategic competence is not limited to attempts at remembering.

Theory-building Typecasting the young child as a passive learner also leads to a view of the young as being dependent on others for opportunities to learn, most notably parents, peers, or teachers. Some have argued that much, if not most, cognitive growth is a result of children internalizing cognitive activities that they originally witness in others (Laboratory of Comparative Human Cognition, 1983; Rogoff and Wertsch, 1984).

Interesting and important though guided learning situations may be, it is clear that much of the time children are also actively involved in orchestrating their own learning. Children learn in situations where there is no obvious guidance, no feedback other than their own satisfaction, and no external pressure to improve or change. They act like scientists, creating theories-in-action (Karmiloff-Smith, 1985) that they challenge, extend, and modify quite on their own. The child is not only a problem-solver but a problem-creator, a metaphor much in keeping with scientific thinking.

Some of the best evidence of self-motivated learning comes from situations in which children are observed as they operate on a problem, over considerable periods of time, quite without external pressure, seemingly with no motivation other than to improve the theory on which they are working. Consider the behavior of 24- to 48-month-old children engaged in free play with a set of nested cups (DeLoache, Sugarman, and Brown, in press). Although the children saw the cups nested before they began to play, there was no real need to renest them; however, they did so, working long and hard in the process.

The most primitive activity, used frequently by children younger than 30 months, was *brute force*. When a large cup was placed on a smaller one, the children would repeatedly twist, bang, or press down hard on the nonfitting cup. A second approach used by some of the younger children was that of *local correction*. After placing two nonfitting cups together, the child separated them and tried to find a replacement for only one cup, a minimal restructuring involving the relation between only two cups at a time. A third characteristic play of children younger than 30 months was to *dismantle the entire set* and start again whenever a cup did not fit.

Older children (30 to 42 months) faced with a nonfitting cup engaged in strategies that involved *consideration of the entire set* of relations in the stack. For example, one sophisticated strategy was *insertion*; the children took apart the stack at a point that enabled them to insert a new cup correctly. A second strategy, *reversal*, was also shown by older children. After placing two nonfitting cups together, the child would immediately reverse the relation between them (5/4 immediately switched to 4/5).

The rapidly executed reversal strategy was not shown by the younger group. Some young children would repeatedly assemble, for example, cups 4-1, starting with 4 as a base and then inserting 3, 2, 1. Then they encountered the largest cup, that is, 5, and attempted to insert it on top of the completed partial stack, pressing and twisting repeatedly. When brute force failed, they would dismantle the whole stack and start again. Similarly, having assembled 1, 2, 4, and 5, and then encountering 3, the younger children's only recourse was to begin again.

The young learners progress from piecemeal activities and local fixup plays to a thoughtful consideration of the relation among elements of the whole problem. There is evidence that this progression reflects a general learning mechanism in action that children of many ages use when faced with novel construction problems. A similar progression is seen in older (four to seven years) children attempting to construct a railway circuit (Karmiloff-Smith, 1979) and even in adolescents refining the processes of written composition (Scardamalia, 1984). It is also important to note that the development on any one task is not completely age-governed in that children left to work on the problem over short periods of time (hours, days, etc.) show the same developmental progression from immature to mature activities that characterizes the cross-age descriptions of initial attacks on the problem (Brown, Kane, and DeLoache, work in progress; Karmiloff-Smith and Inhelder, 1974-1975).

In most of the above examples, children left to work with the problem unaided create solutions, modify their own answers, correct their errors, and develop more mature strategies on their own. Perhaps more impressive cases are those in which children persist after an adequate solution has been reached. Reorganization and improvement in strategies is not solely a response to failure, but often occurs when the child seeks to improve quite adequate functioning procedures. In these cases, it is not failure that directs change but success that the child wishes to refine and extend.

Consider, for example, the group of four- to seven-year-olds who were asked to balance rectangular wooden blocks on a narrow metal rod (Karmiloff-Smith and Inhelder, 1974-1975). These were no ordinary blocks, however. Standard blocks had their weight evenly distributed, and could therefore be balanced at the geometric center. Weighted blocks had the weight of each "side" varied either conspicuously (by gluing a large square block to one end of the base rectangular block) or inconspicuously (by inserting a hidden weight into a cavity on one end); the geometric center rule would not work for these blocks.

At first, the children made the blocks balance by *brute trial and error*. This play was obviously successful; the children balanced each block in turn. This early errorless but unanalyzed phase was spontaneously sup-

planted by the emergence of strong theories-in-action directed at uncovering the rules governing balance in the miniature world of these particular blocks. Unfortunately, they were incomplete hypotheses that produced errors. A common early theory was to concentrate exclusively on the geometric center and attempt to balance all blocks in this fashion. This works only for standard blocks; the weighted blocks were discarded as exceptions ("impossible to balance"), even though the child had previously balanced them all.

After this theory was well established, the child became discomfited by the number and regularity of errors. A new juxtaposed theory was then developed for conspicuously weighted blocks. For these, the children compensated for the weight that was obviously added to one end and adjusted the point of balance accordingly. For a time, however, length and weight were considered independently; standard blocks were balanced by the geometric center rule and conspicuously weighted blocks by the rule of "estimate weight first and then compensate." Hidden weight problems still generated errors; these blocks looked identical to the standard ones and were therefore subjected to the geometric center rule; when they did not conform, they were discarded as anomalies, "impossible to balance."

Now the young theorists were made uncomfortable by the remaining exceptions and began to seek a rule for them. In so doing, a reorganization was induced that resulted in a single rule for all blocks. The children paused before balancing any block and roughly assessed the point of balance. Verbal responses reflected their consideration of both length and weight, e.g., "You have to be careful, sometimes it's just as heavy on each side and so the middle is right, and sometimes it's heavier on one side." After inferring the probable point of balance, and only then, did the child place the block on the bar.

For all of these examples we can ask, why do children bother? Implicit in the situation is the goal that the cups should be nested, the railway constructed, or the blocks balanced; but the children are free to abandon their efforts whenever they like. They persist, however, for long periods, even in the face of frustration and even when an adequate partial solution has been reached.

Pressure to work on adequate partial theories, to produce more encompassing theories, is very similar to what occurs in scientific reasoning. Like the scientist, it is essential that the child first develop simple theories that they perfect and control before they entertain more encompassing complex hypotheses. Karmiloff-Smith and Inhelder refer to this as creative simplification. By ignoring some of the complicating factors initially, the child can begin to construct theories that achieve partial success. Progress comes only when the inadequate partial theory is well established and the learner

attempts to extend the theory to other phenomena. In this way, children or scientists are able to discover new properties that in turn make it possible for new theories to be constructed.

Summary

The studies reviewed in this section make it clear that a universal diagnosis of young children as passive learners, with little control of their own cognitive growth, does serious injustice to their ingenuity. Faced with problems to solve, where they are interested in the outcome and understand the goal, even two-year-olds behave like scientists, actively exploring the environment, testing theories in action, and modifying approaches to problems as a result of experience.

This is not to claim that two-year-olds possess problem-solving abilities comparable to those of the adult, or even of the eight-year-old. Nor is it to claim that preschool theory building is comparable to scientific reasoning perfected during the adolescent, college, and later years. Precursors of active, systematic problem solving emerge early in the child's life, but there are limits on the young child's theory building, and they can have considerable difficulty harnessing their natural proclivities in settings of formal education. These matters are taken up in the fourth section of this essay.

THE TRANSITION TO FORMAL SCHOOLING

Incomplete Knowledge

Young children develop and test theories about the nature of objects, numbers, causality, etc., but these theories are implicit, partial, limited, and sometimes wrong. Their further development depends to some extent on the kind of structured input offered in school, input that makes these theories more precise and explicit.

For example, young children sense that animate and inanimate objects differ, but a great deal more knowledge is needed to develop organized biological theories. Preschool children do not think of animals in the same way that older children and adults in this culture do, i.e., as sharing certain defining biological characteristics (Carey, 1985b). For example, if preschool children are taught that a person has a stomach, they allow that other animals do as well, but inanimate objects do not. However, if they are instead taught that a dog has a stomach, they do not necessarily attribute this to people and other animals. Carey postulates that young children's theory of animates is based on their theory of people and only later on a biological theory.

In a similar vein, preschoolers' understanding of number extends to some but not all situations. For preschoolers, a number is what you get by counting objects in a set. This is a good theory to a degree, but it has limits; for example, it seems to hinder the expansion of the children's number system to include zero and negative numbers. Zero is not a tag that one applies to an item in a set being counted; nor of course is minus one (Evans, 1983).

Misconceptions about the centrality of counting must contribute to systematic errors that elementary school children make in subtraction problems: they are strongly inclined to subtract the smaller digit from the larger, and carrying across zero presents children with unusual difficulty (Brown and VanLehn, 1982; Lindvall and Ibarra, 1981).

Another characteristic difference between the theories of the young and older individuals is in their explicitness. The theories entertained by preschoolers are almost always implicit; they cannot be articulated but nevertheless seem to determine beliefs and actions in a given domain. To illustrate the power of an implicit theory: All English speakers have extensive implicit knowledge of English syntax, knowledge that constrains what we say and understand, but that, in the absence of linguistic instruction, we cannot articulate. No one ever says: "Who did John see Mary and?" but few can articulate the principle of syntax that this utterance violates.

Education often serves to teach the child to make implicit theories explicit. But some theories that the learner is asked to master explicitly conflict with existing implicit theories. For example, theories of mechanics developed early in life may interfere with the learning of formal theories of mechanics. Infants, as we have seen, initiate hand movements to intercept objects on the implicit assumption that they will continue along curvilinear trajectories. McCloskey (1983) suggests that such extrapolations could contribute to a medieval impetus theory of moving objects. There is evidence that students even in high school and college have trouble assimilating Newtonian mechanics because they convert what they are taught into something like the impetus theory. For example, a student who had completed college physics, asked to define momentum, replied: "... A combination of the velocity and the mass of an object. It's something that keeps a body moving." Clearly, he had not grasped the concept of inertia, but like the child or the medieval physicist, considered that some force is always required to keep an object moving at constant velocity.

The spontaneous development of early knowledge structures makes it possible for infants and very young children to acquire rapidly a functional understanding of the world. Yet, these early theories can be two-edged swords; they may sometimes impede children's understanding of explicit theories encountered in the context of formal schooling. Knowing this, we

are in a better position to understand some of the problems children have in school.

The Expansion of Strategic Powers

Young children have considerable strategic skill. Still, they have a long way to go in meeting the demands of literacy. Three-year-olds keep their memory of a hidden toy seem to grasp the rudiments of rehearsal, but this does not mean that they know how to rehearse in a manner that would assist them in learning to spell, or remember historical facts or complex logical or mathematical relations. Gradual refinement and tuning of skills, together with a growing understanding of their function and range of utility, typifies the evolution of many school-relevant learning strategies. An example is skill at learning word lists. Two-year-olds display primitive precursors of rehearsal in their attempts to maintain memory of an object by naming, pointing, or eye fixation (DeLoache et al., 1985). By five years of age, children attempt to name (label) some of the items in a set some of the time (Flavell et al., 1966). Labeling and rote repetition of single items become well established during the early grade-school years (Cruck and Watkins, 1973). With increasing sophistication, children then begin to place more items in their rehearsal sets, engaging in "cumulative rehearsal." During the later primary and early secondary years there is continual refinement of cumulative rehearsal, such as coordinating acquisition and retrieval components and increasingly attending to the size and composition of rehearsal sets (Belmont and Butterfield, 1977). Adolescents use elaborated rehearsal: they become increasingly sensitive to the presence of conceptual organization in the to-be-remembered list and capitalize on this inherent structure whenever possible (Ornstein and Naus, 1978), a development necessary to moving from rehearsal of lists of items and paired associates (as in spelling and foreign language learning) to the learning of whole segments of text. Adequate rehearsal strategies for studying do not appear until well into the high school years and are not perfected even by college students (Brown et al., 1983).

Memory strategies are not the only forms of school-related learning that evolve gradually. Literacy also demands skills of exposition and communication far beyond those expected of the preliterate child. Although young children can take their listeners' knowledge, perspective, and communicative competence into account when attempting to relay a simple message, schools demand much greater sophistication. The student is often required to communicate hazily understood material to an audience that does not share the same background knowledge and assumptions. Schools eventually

require that the student communicate in writing to an unseen, often unknown audience, remote in time and space.

It is useful then to think of competence in terms of bandwidths, the lower end defined by the spontaneous learning of early childhood, the upper end defined by the ever increasing demands of the literate and technological society served by the schools (Brown and Reeve, 1985). Early competence emerges in hospitable contexts that match well with the child's knowledge, interests, and goals: here we see the "tireless explorer" and the "knowledge seeker" (Chukovsky, 1971) in action, the "little scientist" coming to understand his world. In schools, however, the goals and contexts of learning cannot always be of the child's choosing. The goal of learning through spontaneous discovery cannot always be maintained, and students must acquire skills of learning for learning's sake. By its very nature, much of schooling must be divorced from the simple, readily understandable goals of play or work (Bruner, 1972). Formal learning demands that students acquire knowledge without context, and even the preferred structuring of knowledge in temporal, spatial scripts, or story form, must be waived in favor of academic forms of organization by hierarchy and taxonomy (Mandler, 1983). It should not be surprising that many children's natural learning proclivities are overwhelmed by the task of acquiring large amounts of decontextualized material, organized in nonpreferred modes, with demands for precision and processing capacity greater than is the case in everyday life (Bartlett, 1958).

School learners not only must acquire knowledge in specific domains, such as science and history, but they must also "learn how to learn," developing routines for studying in general. More than ever before, schools must equip people to deal with facts that they will encounter only after they leave school. In a scientific and technological society based on an increasingly complex and rapidly changing information base, a productive member of society must be able to acquire new facts, critically evaluate them, and adapt to their implications. Schools need to develop intelligent novices (Brown et al., 1983), those who, although they may not possess the background knowledge needed in a new field, know how to go about gaining that knowledge.

Formal and Informal Teaching

It is not only the type of material to be learned that shifts in the school setting. There is also a substantial change in the teaching procedures compared with informal settings such as homes, preschools, or special interest clubs. In many cultures children are initiated into adult work activities and literacy events without explicit formal instruction. Opportunities for learning

occur primarily in group settings where the adults are primarily responsible for getting the task done. Children participate initially as spectators, later as novices responsible for a little of the work. As children become more experienced and capable of performing more complex tasks that have been demonstrated by adults time and time again, they are gradually ceded greater responsibility. Adults and children come to share the work, with a child taking initiative and an adult correcting and guiding where the child falters. Eventually, the adult gives the child the major active role and adopts the stance of a supportive audience. In these systems of tutelage, learning proceeds at the child's own pace; participation is expected only at a level the child can handle, or a little beyond, thereby presenting a comfortable challenge.

The main features of natural learning situations are thus quite different from formal schooling. In informal learning situations the group has responsibility for getting the job done, or at least an illusion of collective responsibility is maintained. The child joins in, often by self-initiative or with seemingly little adult pressure. Everyone has the same, clearly defined agenda. The adult (parent, expert, master craftsman) models the mature behavior and guides the novice to increasingly more mature participation. There is rarely individual testing; indeed, it is difficult to measure the child's individual contribution because everyone is participating at the same time. The child performs within a limited zone of competence and is rarely called upon to perform beyond capacity; the group does not expose the child's ignorance, but jointly benefits from the child's increasing competence.

Formal schooling makes a sharper distinction between expert and novice status, placing a heavy premium on individual performance. The teacher, the knowledge giver, demonstrates, lectures, and directs the children, the knowledge receivers. Some of these verbal interchanges are unfamiliar. For example, a typical classroom dialogue is the question-answer-evaluation sequence (Mehan, 1979); the teacher addresses a question to a child, receives a response, and evaluates it explicitly ("good") or implicitly (by ignoring the incorrect answer and calling on another child). Typically, children are called upon to perform independently, often when not ready to do so. They do not always know in advance what they will be responsible for and the questions are not always at the appropriate level. They run the risk of failing publicly. Understanding of appropriate turn-taking rituals is acquired slowly by some children, and such practices are even contrary to the approved social patterns of some cultures (Au, 1980; Heath, 1981).

Learned Academic Helplessness

Faced with challenges to their evolving partial theories, preferred learning styles, and modes of interaction, a sizable minority of children react to

schooling by becoming somewhat passive learners. Habitual failure in academic settings erodes their feelings of personal competence. The additional burden of repeated evaluation and labeling that accompanies continued failure is even more damaging. Such children develop quite devastating diagnoses of their own capabilities, readily describing themselves as "dumb," "not good at school things," "too stupid to read," etc. They come to question their personal efficacy (Bandura, 1980) in school settings. Children who view themselves as inadequate in school, as nonstarters in the academic race, often develop compensatory coping strategies to preserve their feelings of self-worth in what they view as the less-than-hospitable environment of the classroom.

Negative conceptions of one's prognosis for school success lead at best to defensive "passing," "coping," or "managing" (Goffman, 1963). Coping strategies include systematic devaluation of academic tasks and goals and the justification of lack of effort, i.e., "who needs to read anyways." Passing and managing tactics can be perfected so that the wily child avoids occasions of challenge. Threatening tests can be avoided if other children will cover; teachers will avoid embarrassment by not calling on the weaker child (Cole and Traupmann, 1980). All these ploys serve to defend against damaging expositions, attributions of failure, and further erosion of self-efficacy. These defenses are also formidable barriers to learning. Orienting one's attention and effort in school to minimizing demonstrations of failure rather than actively seeking occasions for acquiring new knowledge may be a realistic reaction to repeated obstacles, but it is not conducive to new learning.

Failure-oriented children typically display a pattern of learned helplessness in the face of obstacles or errors (Seligman et al., 1971). This pattern also increases negative feelings and further deflates the prognosis for success. There is a concomitant degradation of learning strategies. Failure-oriented children attribute their errors to lack of ability and often view temporary failure as an indication of a stable, generalized incompetence ("I'm dumb."). Helpless children question their ability in the face of obstacles, perceiving past successes to be few and irrelevant and future effort to be futile (Dweck and Bempechat, 1983).

In contrast, mastery-oriented children treat obstacles as challenges to be overcome by perfecting one's learning strategies; they do not attribute a temporary setback to personal shortcomings. Their verbalizations following failure often consist of positive self-instruction: "Slow down," "try new tactics," "evaluate the task more systematically." Dweck and Bempechat (1983) argue that these different reactions to academic difficulties reflect whether the child conceives tasks in terms of performance goals, where competence is to be evaluated and perhaps found wanting, or learning goals,

where an opportunity exists to acquire new competences. Performance-goal children feel that they have been successful when they "don't make mistakes," "get easy work," etc. whereas learning-goal children feel successful when they master a new skill.

Reawakening the Active Learner

To be successful, interventions with passive learners must reestablish the confidence necessary for self-directed learning. Wertine (1979) has argued that many students need help to increase their "courage spans," enabling them to treat failures as false starts or blind alleys that can be overcome and to regard errors as useful information. Students need to tolerate ambiguity, evaluate and judge information, and seek disconfirming evidence—in short, become critics and especially self-critics (Binet, 1909; Brown, 1985). But this criticism must be constructive, mastery-oriented self-guidance rather than self-derogation.

To end on an optimistic note we will illustrate two methods that have achieved some success at acclimatizing children to formal learning settings: (a) avoiding initial failures by adapting early school experiences to the prior competence of the entering child; and (b) lessening the gap between informal and formal teaching styles.

An excellent example of matching classrooms to homes is Heath's work with poor black Appalachian kindergarten children entering classrooms of white middle-class teachers (Heath, 1981). Heath found systematic differences between questioning behavior in the black and white communities she studied, particularly a mismatch between classroom questioning routines and spontaneous questioning activities in black preschoolers' environments. A common classroom routine is the "known-answer" question. Teachers routinely call on children to answer questions in order to display the children's knowledge rather than to provide information that the teacher does not have, which is the more familiar purpose of a question. These classroom questioning patterns do not map well into the earlier experiences of many children who lack informal exposure to academic language games.

At the beginning of the study Heath found that teachers were bewildered by the lack of responsiveness of their black pupils. For example: "They don't seem to be able to answer even the simplest questions." "I would almost think they have a hearing problem; it's as if they don't hear me ask a question." "I sometimes feel that when I look at them and ask a question, I'm staring at a wall I can't break through" (Heath, 1981:108).

Heath shared with teachers her documentation of the types of preschool questioning these children were familiar with, such as metaphoric and narrative sequences, and encouraged them to engineer settings that evoked

the children's competence in the familiar format. Having practiced familiar questioning rituals, the teachers were then able to introduce the unfamiliar known-answer routines with great success. Another case of easing the transition to formal schooling, by capitalizing on the children's strengths rather than exposing their weaknesses, is the remarkable gains in reading achievement shown by Native Hawaiian (Polynesian) children after reading lessons were set in the context of a familiar Hawaiian interactive game, "talk-story" (Au, 1980).

Another successful intervention ploy is to lessen the gap between informal and formal learning settings. As we have seen, natural tutoring involves modeling on the part of the teacher and a gradual transfer of responsibility to the novices when and if they are ready to take control of their own learning. Instructional routines that mimic natural tutoring sessions are proving quite successful. For example, junior high school "passive" learners with depressed reading comprehension scores were moved from traditional instruction to a reciprocal teaching environment based on theories of natural tutoring. In reciprocal teaching, students of varying levels of competence and an adult teacher take turns "being the teacher," that is, leading a dialogue on a segment of text they are jointly attempting to understand and remember. The teacher responsible for a particular segment of text leads the ensuing dialogue by stating the gist in his or her own words, posing a question, clarifying any misunderstandings, and predicting what might happen next. All of these activities are part of a natural dialogue between the adult teacher and students. If a student has difficulty with any component of the dialogue, the teacher provides modeling and feedback at the student's current level, gradually leading each student to independent competence. Examples of such gradual transfer of responsibility can be found in Palincsar and Brown (1984).

Reciprocal teaching is based on certain central principles of effective learning: (1) the teacher models the desired comprehension activities, thereby making underlying processes overt, explicit, and concrete; (2) the teacher demonstrates the activities in appropriate contexts, not as isolated decontextualized skills; (3) the students are fully informed of the need for strategic intervention and the range of utility of a particular strategy; (4) the students see immediately that the use of strategies works for them; (5) the responsibility for the comprehension activities is transferred to the students as soon as they can take charge of their own learning; (6) this transfer of responsibility is gradual, presenting students with a comfortable challenge; and (7) feedback is tailored to the students' existing levels, encouraging them to progress one more step toward competence.

The reciprocal teaching procedure involves continuous trial and error on the part of the student, coupled with continuous adjustment on the part of

the teacher to the student's current competence. Through interactions with the supportive teacher and their more knowledgeable peers, the students are led to perform at an increasingly more mature level; sometimes this progress is fast, sometimes slow, but, irrespective of the rate, the teacher provides an opportunity for the students to respond at a slightly challenging level. As the students master one level of involvement, the teacher increases his demands so that the students are gradually called upon to adopt the adult role fully and independently. The teacher then fades into the background as the students take charge of their own learning from texts.

The results of the reciprocal teaching intervention with junior high schoolers were dramatic. The students improved their ability to clarify, predict, summarize, and ask questions. Consider the quality of the summaries; these seventh-grade students initially produced summaries ranked inadequate even by the standards set by fifth graders. At the end of two weeks of daily reciprocal teaching sessions, they were able to produce quite acceptable inventions, i.e., summaries, in their own words, of the gist of a particular dialogue. A predominance of inventions characterizes the untrained summarization performance of college freshmen (Brown and Day, 1983). Thus, guided instruction had taken these failing seventh graders to a level of competence far beyond that typical for their peers. Furthermore, they also became able to assume the role of teacher, producing their own questions and summaries and evaluating those of others. In addition, there were significant improvements in independent performance on laboratory, classroom, and standardized tests of comprehension. But perhaps more importantly, the children's feelings of personal competence and control improved dramatically. Allowed to take charge of the dialogues, and even tutor less advanced students, these "failing" students increased their courage as well as their purely cognitive skills. Success bred positive expectations from teachers and improved students' personal "efficacy," i.e., the confidence to employ active learning strategies in the belief that they will work.

It is important to note that mimicking natural tutoring styles has proved a successful instructional technique in areas other than reading: listening comprehension (Brown and Palincsar, in press), writing (Applebee and Langer, 1983; Scardamalia, 1984), storytelling (McNamee, 1981), studying (Fraser and Schwartz, 1976), and problem solving (Bloom and Broder, 1950) have all responded well to reciprocal instruction strategies. In addition, it is not only teachers who can serve as the agent of change but also mothers (Ninio and Bruner, 1978; Saxe et al., 1984; Scollon, 1976; Wertsch, 1979), peers (Bloom and Broder, 1950; Whimbey and Lochhead, 1982), and even somewhat intelligent computer tutors (Brown et al., 1982; Heller and Hungate, 1984; Lesgold and Reif, 1983). The concept of expert scaffolding,

the gradually guided transfer of learning responsibility from an expert to a novice, has wide applicability as an instructional philosophy.

Summary

Recognition of children's natural competence, both in terms of strategic rules and knowledge, is having a profound effect on instructional theory. Structured instruction, however, is necessary for the child to go beyond imprecise, and sometimes erroneous, implicit theories and to acquire the precise, explicit theories that constitute formal knowledge. Through the intervention of certain forms of formal schooling, children are turned into *routine school experts* (Hatano, 1982), able to perform, more and more efficiently, the procedures taught and practiced in schools.

One problem, however, is that routine expertise can lead to the acquisition of "inert knowledge" (Whitehead, 1916), acquired by rote learning and practice but rarely used flexibly and creatively. Educational systems that promote *adaptive expertise* (Hatano, 1982), whereby students come to understand, challenge, and flexibly apply their knowledge, depend on maintaining the active thirst for knowledge that the preschool child brings initially into settings of formal education. The more we learn about the knowledge structures that children bring to school and the instructional practices that foster their natural proclivities to build and refine theories, the more able we will be to design instructional modes that promote adaptive expertise rather than the acquisition of inert knowledge.

CONCLUSION

In this chapter we have concentrated on an apparent paradox concerning the cognitive competence of children. Recent research with infants and very young children suggests that they know far more about their world initially, and develop this understanding more rapidly, than was previously supposed. However, topical consternation over the putatively increasing incompetence of school-aged children in academic settings stands in sharp contrast to these claims of early ingenuity.

In the first part of the chapter, we discussed the necessity of granting complex cognitive structures to the young human mind. This breaking away from an empiricist account of human thought took its impetus from sweeping changes in psychological theory pioneered notably by Chomsky, the Gibsons, and Piaget. Buttressing these theoretical claims is a body of contemporary research gleaned from a variety of ingenious techniques that make it increasingly feasible to interrogate infants. The outcome of a painstaking

set of inquiries is a window through which we can view the young child's cognitive world, a window that is only beginning to open.

We now know that infants are sensitive to certain principles of movement early in life; that they garner multisensory and multimodal information about the nature of objects; that they endow objects with properties of rigidity and solidity; and that they possess rudimentary theories of categories, recognizing properties of sets of nonidentical objects, including numerosity, a property of sets divorced from any description of the objects themselves. Implicit principles of causality, numerosity, etc. guide the development of such knowledge at a rapid pace during the preschool years, a time during which children are busily engaged in exploring their environment. Characterized as "tireless explorers," they invent primitive but serviceable comprehension, learning, and memory strategies, and create and test continuously evolving theories to breathe meaning into their physical and social world.

The pace of this development seems to slow down during the school years, but this may be because children's competence is increasingly viewed in the light of their performance on academic tests. Learning in schools differs from natural learning in that others are in charge of what must be learned, others control the timetable, and students must develop interest and skill in learning for learning's sake so that they can intentionally set about acquiring large bodies of decontextualized knowledge.

In an increasingly complex and rapidly changing technological society, more than ever before, students must be equipped to acquire new information, critically evaluate it, and adapt to its implications. They must learn to waive their imprecise theories in favor of the precise, explicit, more encompassing theories that constitute formal knowledge. Profound theory change of this magnitude comes at a cost that many may be reluctant to pay without a supportive academic environment. In the latter part of the chapter, we discussed innovative pedagogical procedures that serve to maintain and bolster the child's natural curiosity and theory-building capacities. In the exploitation of such techniques lies hope for solving the paradox of early competence and later academic crisis.

REFERENCES

- Applebee, A. N., and Langer, J. A.
1983 Instructional scaffolding: reading and writing as natural language activities. *Language Arts* 60:168-175.
- Aslin, R. N., Pisoni, D. B., and Jusczyk, P. W.
1983 Auditory development and speech perception in infancy. In M. M. Haith and J. C. Campos, eds., *Handbook of Child Psychology*. Vol. 2. *Infancy and Developmental Psychobiology*. New York: John Wiley and Sons.

- Au, K. H.
1980 A Test of the Social Organizational Hypothesis: Relationships Between Participation Structures and Learning to Read. Unpublished doctoral dissertation, University of Illinois.
- Baillargeon, R., Spelke, E. S., and Wasserman, S.
In press Object permanence in 5-month-old infants. *Cognition*.
- Bandura, A.
1980 Self-referent thought: the development of self-efficacy. In J. H. Flavell and L. D. Ross, eds., *Development of Social Cognition*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Bartlett, F. C.
1958 *Thinking: An Experimental and Social Study*. New York: Basic Books.
- Belmont, J. M., and Butterfield, E. C.
1977 The instructional approach to developmental cognitive research. In R. V. Kail, Jr., and J. W. Hagen, eds., *Perspectives on the Development of Memory and Cognition*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Binet, A.
1909 *Les Idées Modernes sur les Enfants*. Paris: Ernst Flammarion.
- Bjork, E. L., and Cummings, E. M.
1984 Infant search errors: stage of concept development or stage of memory development. *Memory & Cognition* 12(1):1-192.
- Bloom, B. S., and Broder, L. J.
1950 *Problem Solving Processes of College Students*. Chicago: University of Chicago Press.
- Braine, M. D. S., and Rumain, B.
1983 Logical reasoning. In J. H. Flavell and E. M. Markman, eds., *Handbook of Child Development* (4th ed.). Vol. 3. New York: John Wiley and Sons.
- Brown, A. I.
1975 The development of memory: knowing, knowing about knowing, and knowing how to know. In H. W. Reese, ed., *Advances in Child Development and Behavior*. Vol. 10. New York: Academic Press.
- 1985 Mental orthopedics: a conversation with Alfred Binet. In S. Chipman, J. Segal, and R. Glaser, eds., *Thinking and Learning Skills: Current Research and Open Questions*. Vol. 2. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Brown, A. I., and Day, J. D.
1983 Macrostrates for summarizing texts: the development of expertise. *Journal of Verbal Learning and Verbal Behavior* 22:1-14.
- Brown, A. I., and DeLoache, J. S.
1978 Skills, plans, and self-regulation. In R. Siegler, ed., *Children's Thinking: What Develops?* Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Brown, A. I., and Palincsar, A. S.
In press Reciprocal teaching of comprehension strategies: a natural history of one program for enhancing learning. In J. Barkowski and J. D. Day, eds., *Intelligence and Cognition in Special Children: Comparative Studies of Giftedness, Mental Retardation, and Learning Disabilities*. New York: Ablex.
- Brown, A. I., and Reeve, R. A.
1985 Bandwidths of competence: the role of supportive contexts in learning and development. In L. S. Liben and D. H. Feldman, eds., *Development and Learning: Conflicts or Congruance?* Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Brown, A. I., Bransford, J. D., Ferrara, R. A., and Campione, J. C.
1983 Learning, remembering, and understanding. In J. H. Flavell and E. M. Markman, eds., *Handbook of Child Psychology* (4th ed.). Vol. 3. *Cognitive Development*. New York: John Wiley and Sons.

- Brown, J.S., and VanLehn, K.
1982 Toward a generative theory of "bugs." In T.P. Carpenter, J.M. Moser, and T.A. Romberg, eds., *Addition and Subtraction: A Cognitive Perspective*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Brown, J.S., Burton, R.R., and deKleer, J.
1982 Pedagogical, natural language and knowledge engineering techniques in SOPHIE I, II and III. In D. Sleeman and J.S. Brown, eds., *Intelligent Tutoring Systems*. New York: Academic Press.
- Bruner, J.S.
1972 Nature and uses of immaturity. *American Psychologist* 27:687-708.
- Bullock, M.
In press Preschoolers' understanding of causal connections. *British Journal of Developmental Psychology*.
- Bullock, M., Gelman, R., and Baillargeon, R.
1982 The development of causal reasoning. In J. Friedmann, ed., *The Developmental Psychology of Time*. New York: Academic Press.
- Carey, S.
1985a Are children fundamentally different kinds of thinkers and learners than adults? In S. Chipman, J. Segal, and R. Glaser, eds., *Thinking and Learning Skills*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- 1985b *Conceptual Change in Childhood*. Cambridge, Mass.: MIT Press/Bradford.
- Chomsky, N.
1957 *Syntactic Structures*. The Hague: Mouton.
- Chukovsky, K.
1971 *From Two to Five* (revised ed.). Berkeley: University of California Press. Translation by Miriam Morton, 1963.
- Cole, M., and Traupmann, K.
1980 Comparative cognitive research: learning from a learning disabled child. In A. Collins, ed., *Minnesota Symposium on Child Development*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Craik, F.I.M., and Watkins, M.J.
1973 The role of rehearsal in short-term memory. *Journal of Verbal Learning and Verbal Behavior* 12:599-607.
- DeLoache, J.S., Cassidy, D.J., and Brown, A.L.
1985 Precursors of mnemonic strategies in very young children's memory. *Child Development* 56:125-137.
- DeLoache, J.S., Sugarman, S., and Brown, A.L.
In press The development of error correction strategies in young children's manipulative play. *Child Development*.
- Donaldson, M.A.
1978 *Children's Minds*. New York: Norton.
- Dweck, C.S., and Bempechat, J.
1983 Children's theories of intelligence: consequences for learning. In S.G. Paris, G.M. Olson, and H.W. Stevenson, eds., *Learning and Motivation in the Classroom*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Eimas, P.D., Siqueland, E.R., Jusczyk, P.W., and Vigorito, J.
1971 Speech perception in infants. *Science* 171:303-306.
- Evans, D.W.
1983 Understanding Zero and Infinity in the Early School Years. Unpublished doctoral dissertation. University of Pennsylvania, Philadelphia.

- Fantz, R.L.
1961 The origins of form perception. *Scientific American* 204:66-72.
- 1966 Pattern discrimination and selective attention as determinants of perceptual development from birth. In A.H. Kidd and J.L. Rivoire, eds., *Perceptual Development in Children*. New York: International Universities Press.
- Field, D.
1978 How children in ESN schools in London learn conservation skills. In G.L. Lubin, M.K. Paulsen, J.F. Magary, and M. Soto-McAlister, eds., *Piagetian Theory and Its Implications for the Helping Professions*. Proceedings of the Seventh Inter-disciplinary Conference. Vol. 2. Los Angeles: University of Southern California Press.
- Field, J., Muir, D., Pilon, R., Sinclair, M., and Dowdell, P.C.
1980 Infants' orientation to lateral sounds from birth to three months. *Child Development* 50:295-298.
- Flavell, J.H.
1970a Concept development. In P.H. Mussen, ed., *Carmichael's Manual of Child Psychology*. Vol. 1. New York: John Wiley and Sons.
- 1970b Developmental studies of mediated memory. In H.W. Reese and L.P. Lipsitt, eds., *Advances in Child Development and Behavior*. Vol. 5. New York: Academic Press.
- Flavell, J.H., Beach, D.H., and Chinsky, J.M.
1966 Spontaneous verbal rehearsal in memory tasks as a function of age. *Child Development* 37:283-299.
- Frase, L.T., and Schwartz, B.J.
1975 The effect of question production and answering on prose recall. *Journal of Educational Psychology* 62:628-635.
- Gelman, R.
1977 How young children reason about small numbers. In N.J. Casellan, D.B. Pisoni, and G.R. Potts, eds., *Cognitive Theory*. Vol. 2. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- 1978 Cognitive development. *Annual Review of Psychology* 29:297-332.
- Gelman, R., and Gallistel, C.R.
1978 *The Child's Understanding of Number*. Cambridge, Mass.: Harvard University Press.
- Gelman, R., and Meck, E.
1983 Preschoolers counting: principles before skill. *Cognition* 13:343-359.
- Gelman, R., Spelke, E.S., and Meck, E.
1983 What preschoolers know about animate and inanimate objects. In D. Rogers and J.A. Sloboda, eds., *The Acquisition of Symbolic Skills*. London: Plenum.
- Gibson, E.J., and Spelke, E.S.
1983 The development of perception. In J.H. Flavell and E.M. Markman, eds., *Handbook of Child Psychology* (4th ed.). Vol. 3. *Cognitive Development*. New York: John Wiley and Sons.
- Gibson, E.J., and Walker, A.S.
1984 Intermodal perception of substance. *Child Development* 55:453-460.
- Goffman, E.
1963 *Stigma: Notes on the Management of Spoiled Identity*. Englewood Cliffs, N.J.: Prentice-Hall.
- Greene, J.G., Riley, M.S., and Gelman, R.
1984 Conceptual competence and children's counting. *Cognitive Psychology* 16:94-143.
- Green, G.F., and Resnick, L.B.
1977 Can preschool children invent addition algorithms? *Journal of Educational Psychology* 69:645-652.

- Harris, P.L.
1983 Infant cognition. In M. Milaith and S.S. Campos, eds., *Handbook of Child Psychology* (4th ed.). Vol. 2. *Infancy and Developmental Psychobiology*. New York: John Wiley and Sons.
- Huano, G.
1982 Cognitive consequences of practice in culture specific procedural skills. *The Quarterly Newsletter of the Laboratory of Comparative Human Cognition* 4:15-18.
- Health, S.B.
1981 Questioning at home and at school: a comparative study. In G. Spindler, ed., *Doing Ethnography: Educational Anthropology in Action*. New York: Holt, Rinehart and Winston.
- Heller, J.I., and Hungate, H.N.
1984 Computer-based Expert Scaffolding. Unpublished manuscript. University of California, Berkeley.
- Hood, L., and Bloom, L.
1979 What, when and how about why: a longitudinal study of early expressions of causality. *Monographs of the Society for Research in Child Development* 44 (Serial No. 181, No. 6).
- Kagan, J., Kearsley, R.B., and Zelazo, P.R.
1978 *Infancy, Its Place in Human Development*. Cambridge, Mass.: Harvard University Press.
- Kail, R.V., Jr., and Hagen, J.W., eds.
1977 *Perspectives on the Development of Memory and Cognition*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Kalmins, I.V., and Bruner, J.S.
1973 The coordination of visual observation and instrumental behavior in early infancy. *Perception* 2:307-314.
- Kamiloff-Smith, A.
1979 Problem solving construction and representations of closed railway circuits. *Archives of Psychology* 47:37-59.
- 1985 Children's problem solving. In M. Lamb, A.L. Brown, and B. Rogoff, eds., *Advances in Developmental Psychology*. Vol. 3. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Kamiloff-Smith, A., and Inhelder, B.
1974- If you want to get ahead, get a theory. *Cognition*, 3, pp. 195-212.
- 1975
- Keil, F.C.
1979 *Semantic and Conceptual Development*. Cambridge, Mass.: Harvard University Press.
- 1981 Constraints on knowledge and cognitive development. *Psychological Review* 88:197-227.
- Kessen, W., Salapatek, P.H., and Haith, M.M.
1972 The visual response of the human newborn to linear contour. *Journal of Experimental Child Psychology* 13:19-20.
- Klahr, D., and Wallace, J.G.
1976 *Cognitive Development, an Information Processing View*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Koslowski, B., Spilton, D., and Snipper, A.
1981 Children's beliefs about instances of mechanical and electrical causation. *Journal of Applied Developmental Psychology* 2:189-210
- Laboratory of Comparative Human Cognition
1983 Culture and cognitive development. In P.H. Mussen, ed., *Handbook of Child Psychology* (4th ed.). Vol. 1. *History, Theory, and Methods*. New York: John Wiley and Sons

- Landau, B., Gleitman, H., and Spelke, E.S.
1981 Spatial knowledge and geometric representation in a child blind from birth. *Science* 213:1275-1278.
- Lempers, J.D., Flavell, E.R., and Flavell, J.H.
1977 The development in very young children of tacit knowledge concerning visual perception. *Genetic Psychology Monographs* 95:3-53.
- Lesgold, A.M., and Reif, F.
1983 *Computers in Education: Realizing the Potential*. (Report of 1982 Pittsburgh Research Conference, U.S. Department of Education). Washington, D.C.: U.S. Government Printing Office.
- Lindvall, C.M., and Ibarra, C.G.
1981 Incorrect Procedures Used by Primary Grade School Pupils in Solving Open Addition and Subtraction Sentences. Manuscript, Learning, Research and Development Center, University of Pittsburgh, Pittsburgh, Pa.
- Mandler, J.M.
1983 Representation. In J.H. Flavell and E.M. Markman, eds., *Handbook of Child Psychology*. (4th ed.). Vol. 3. *Cognitive Development*, pp. 420-494. New York: John Wiley and Sons.
- Markman, E.M.
1981 Two different principles of conceptual organization. In M.E. Lamb and A.L. Brown, eds., *Advances in Developmental Psychology*. Vol. 1. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- McCloskey, M.
1983 Naive theories of motion. In D. Gentner and A.L. Stevens, eds., *Mental Models*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- McNamee, G.D.
1981 Social Origins of Narrative Skills. Paper presented at April meeting of the Society for Research in Child Development, Boston.
- Michan, H.
1979 *Learning Lessons: Social Organization in the Classroom*. Cambridge, Mass.: Harvard University Press.
- Meltzoff, A.N., and Burton, R.
1979 Intermodal matching by human neonates. *Nature* 282:403-404.
- Mendelson, M.J., and Haith, M.M.
1976 The relation between audition and vision in the human newborn infant. *Monographs of the Society for Research in Child Development* 41 (4, Serial No. 167).
- Nelson, K., and Gruenel, J.
1981 Generalized event representations: basic building blocks of cognitive development. In M.E. Lamb and A.L. Brown, eds., *Advances in Developmental Psychology*. Vol. 1, pp. 131-158. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Ninio, A., and Bruner, J.S.
1978 The achievement and antecedents of labelling. *Journal of Child Language* 5:1-15.
- Ornstein, P.A., and Naus, M.J.
1978 Rehearsal processes in children's memory. In P.A. Ornstein, ed., *Memory Development in Children*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Palincsar, A.S., and Brown, A.L.
1984 Reciprocal teaching of comprehension-fostering and monitoring activities. *Cognition and Instruction* 1(2):117-175.
- Piaget, J.
1954 *The Construction of Reality in the Child*. New York: Basic Books.
- 1980 *Experiments in Contradiction*. Chicago and London: University of Chicago Press.

- Premack, D.
1976 *Intelligence in Ape and Man*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Rugoff, B., and Wertsch, J.V., eds.
1984 *Children's Learning in the "Zone of Proximal Development"*. San Francisco: Jossey-Bass.
- Rosch, E., Mervis, C.B., Gray, W.D., Boyes-Braem, P., and Johnson, D.M.
1976 Basic objects in natural categories. *Cognitive Psychology* 8:382-439.
- Ross, G.S.
1980 Categorization in 1- to 2-year-olds. *Developmental Psychology* 16:391-396.
- Saxe, G.B., Gearhart, M., and Guberman, S.R.
1984 The social organization of early number development. In B. Rogoff and J. Wertsch, eds., *Children's Learning in the "Zone of Proximal Development"*. San Francisco: Jossey-Bass.
- Scardamalia, M.
1984 Knowledge Telling and Knowledge Transforming in Written Composition. Paper presented at the meeting of the American Educational Research Association, New Orleans.
- Scollon, R.
1976 *Conversations with a One-Year-Old*. Honolulu: University Press of Hawaii.
- Seligman, M.E.P., Maier, S.F., and Solomon, F.L.
1971 Unpredictable and uncontrollable aversive events. In S.R. Brush, ed., *Aversive Conditioning and Learning*. New York: Academic Press.
- Shultz, M.
1978 The relationship between cognitive processes and the development of communication skills. In B. Keasey, ed., *Nebraska Symposium on Motivation*. Lincoln: University of Nebraska Press.
- Shultz, T.R.
1982 Rules of causal attribution. *Monographs of the Society for Research in Child Development* 47 (1, Serial No. 194).
- Stegler, R.S., and Robinson, M.
1982 The development of numerical understandings. In H.W. Reese, ed., *Advances in Child Development and Behavior*. Vol. 16. New York: Academic Press.
- Simon, H.A.
1972 On the development of the processor. Pp. 3-22 in S. Farnham-Diggory, ed., *Information Processing in Children*. New York: Academic Press.
- Sophian, C.
1984 Developing search skills in infancy and early childhood. In C. Sophian, ed., *Origins of Cognitive Skills*. Hillsdale, N.J.: Lawrence Erlbaum Associates.
- Spelke, E.S.
1976 Infants' intermodal perception of events. *Cognitive Psychology* 8:553-560.
- Starkey, P., and Cooper, R.G.
1980 Numerosity perception in human infants. *Science* 210:1033-1035.
- Starkey, P., Spelke, E.S., and Gelman, R.
1983 Detection of 1:1 correspondences by human infants. *Science* 222:79-81.
- Stein, N.L.L., and Trabasso, T.
1982 What's in a story: an approach to comprehension and instruction. In R. Glaser, ed., *Advances in the Psychology of Instruction*. Vol. 2. Norwood, N.J.: Ablex.
- Stevenson, H.W.
1970 Children's learning. In P.H. Mussen, ed., *Manual of Child Psychology*. 3rd ed. New York: John Wiley and Sons.

- Strauss, M.S., and Curtis, L.E.
1981 Infant perception of numerosity. *Child Development* 52:1146-1152.
- Tronick, E., Adamson, L., Wise, S., Als, H., and Brazelton, T.B.
1975 The Infant's Response to Entrapment Between Contradictory Messages in Face to Face Interaction. Paper presented at the meeting of the Society for Research in Child Development, Denver.
- Von Hofsten, C.
1980 Predictive reaching for moving objects by human infants. *Journal of Experimental Child Psychology* 30:369-382.
- Vygotsky, L.S.
1962 *Thought and Language*. Cambridge, Mass.: MIT Press.
- Wanner, E., and Gleitman, L.R., eds.
1982 *Language Acquisition: The State of the Art*. Cambridge, England: Cambridge University Press.
- Wellman, H.M., Ritter, R., and Flavell, J.H.
1975 Deliberate memory behavior in the delayed reactions of very young children. *Developmental Psychology* 11:780-787.
- Wenheimer, M.
1961 Psychomotor coordination of auditory-visual space at birth. *Science* 134.
- Wentme, R.
1979 Students, problems, and courage spans. In I. Lockhead and J. Clement, eds., *Cognitive Process Instruction: Research on Teaching Thinking Skill*. Philadelphia: Franklin Institute Press.
- Wertsch, J.V.
1979 From social interaction to higher psychological processes: a clarification and application of Vygotsky's theory. *Human Development* 22:1-22.
- Whimby, A., and Lockhead, J.
1982 *Problem Solving and Comprehension*. Philadelphia: Franklin Institute Press.
- White, S.H.
1965 Evidence for hierarchical arrangement of learning processes. In L.L. Lipsitt and C.C. Spiker, eds., *Advances in Child Development and Behavior*. Vol. 2. New York: Academic Press.
- 1970 The learning theory tradition for child psychology. In P.H. Mussen, ed., *Carmichael's Manual of Child Psychology*. Vol. 1. New York: John Wiley and Sons.
- Whitehead, A.N.
1916 The Aims of Education. Presidential Address to the Mathematical Association of England.
- Whorf, B.L.
1956 *Language, Thought and Reality*. John B. Carroll, ed. Cambridge, Mass.: MIT Press.