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Initial knowledge: six suggestions

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Abstract

Although debates continue, studies of cognition in infancy suggest that knowledge begins to emerge early in life and constitutes part of humans' innate endowment. Early-developing knowledge appears to be both domain-specific and task-specific, it appears to capture fundamental constraints on ecologically important classes of entities in the child's environment, and it appears to remain central to the common-sense knowledge systems of adults.

1. Introduction

The study of initial knowledge generates controversies that extend to its foundations. There is no consensus among investigators of cognitive development about when knowledge begins, what it consists of, how it manifests itself, what causes it to emerge, how it changes with growth and experience, or what roles it plays in the development of thought and action. Fortunately, these controversies have not led to an impasse: studies of the early development of knowledge have been especially intense and fruitful over the last quarter century. These studies suggest a view of early cognitive development that addresses the above questions. I sketch this view by offering six suggestions about initial knowledge and its subsequent growth.

2. Knowledge emerges early in development

When can a creature be said to know something about its surroundings? One

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stringent but useful answer is, when the creature systematically draws on what it knows to make inferences about properties of the surroundings that it cannot perceive (Piaget, 1954). By this standard, 3-month-old human infants appear to have developed knowledge of physical objects (Baillargeon & DeVos, 1991), people (Legerstee, in press), number (Wynn, 1992), and space (Kellman, 1993).

A study of knowledge of physical objects serves as an example. Ball (1973) presented infants at a range of ages with an event in which one object moved out of view behind a screen and then a second object, which was stationary and half-hidden at the opposite side of the screen, began to move in the same direction (Fig. 1). The spatio-temporal relation of the object motions led adults to infer that the first object hit the second object. Ball investigated whether infants also made this inference, by presenting infants with the partially hidden event repeatedly until their interest in this event declined, as evidenced by a decline in looking time. Then he presented fully visible events in which the two objects either came into contact or stopped short of one another (Fig. 1). Looking times to the two test events were compared with the looking times of infants in a control condition, who viewed the same test events but were not first familiarized with the partly hidden event. If the infants who viewed the partly hidden event inferred

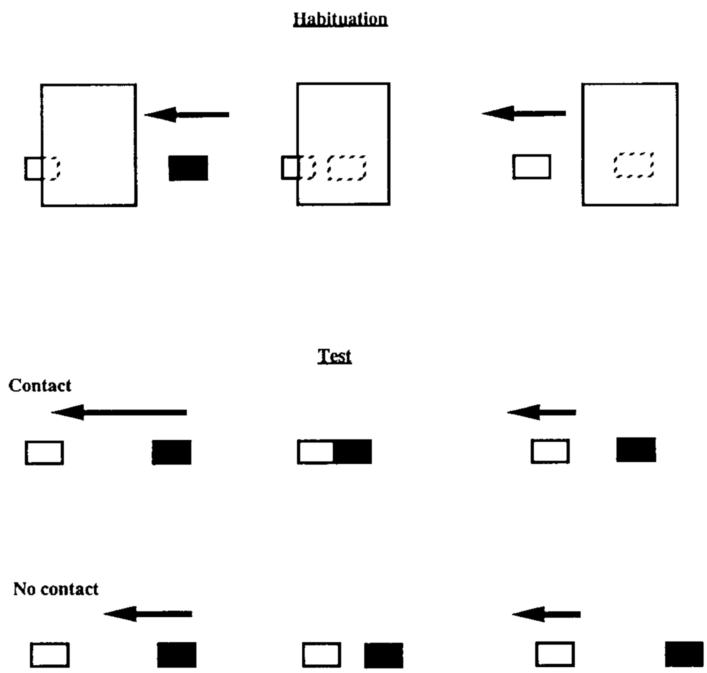

Fig. 1. *Displays for a study of infants' reasoning about hidden object motion. Diagrams depict the beginning (left), middle, and end (right) of each event. Arrows above an object indicate the direction of motion of that object; dotted lines indicate the occluded portions of an object (after Ball, 1973)*

that the first object hit the second object while it was out of view, they were expected to look longer than the control subjects at the test event in which the objects failed to make contact, because of its greater novelty. This preference was obtained in Ball's experiment and in a recent replication (Van de Walle, Woodward, & Phillips, 1993). The findings provide evidence that infants make inferences about the unperceived motions of objects, in accord with the principle that objects do not act upon each other at a distance. That suggestion has since been corroborated and extended by a variety of experiments using different displays and procedures to tap the same competence in infants as young as 3 months of age (for reviews, see Baillargeon, in press; Leslie, 1988, 1994; Spelke & Van de Walle, 1993).

At 3 months, infants have limited abilities to perceive objects by looking (Banks & Salapatek, 1983) or by touching (Streri, 1993), and they have limited abilities to act on objects (Piaget, 1952). The early emergence of knowledge of object motion therefore suggests that perceiving, acting, and reasoning develop in synchrony over the infancy period. This suggestion challenges the traditional view that psychological and neural development proceed from peripheral to central structures, such that humans first sense things and respond to them reflexively, later perceive things and act on them adaptively, and finally begin to think about things that leave their view. Evidence for the synchronous development of perception, action, and thought is consistent with findings from anatomical studies of the developing cortex, showing synchronous growth of the areas involved in these functions (Rakic, in press). This evidence invites us to view the development of cognition in the same kinds of ways that we view the development of other biological and psychological processes (Chomsky, 1980).

3. Initial knowledge is domain-specific

Human infants do not appear to develop knowledge about all the entities they perceive. As far as we can tell, infants lack systematic knowledge of shadows (Spelke, Phillips, & Woodward, in press) and plants (Carey, 1985), and they may not distinguish in their reasoning between the actions of humans and other animals (see Premack, 1990). In contrast, young infants appear to have systematic knowledge in four domains: physics, psychology, number, and geometry.

The clearest evidence that human cognition is built on domain-specific systems of knowledge comes from studies of the principles that guide infants' reasoning in these four domains. In the domain of physics, young infants appear to make inferences about the hidden motions of inanimate, material objects in accord with three principles: cohesion (objects move as connected, bounded units), continuity (objects move on connected, unobstructed paths), and contact (objects affect one another's motion if and only if they touch) (Fig. 2). In contrast, these principles

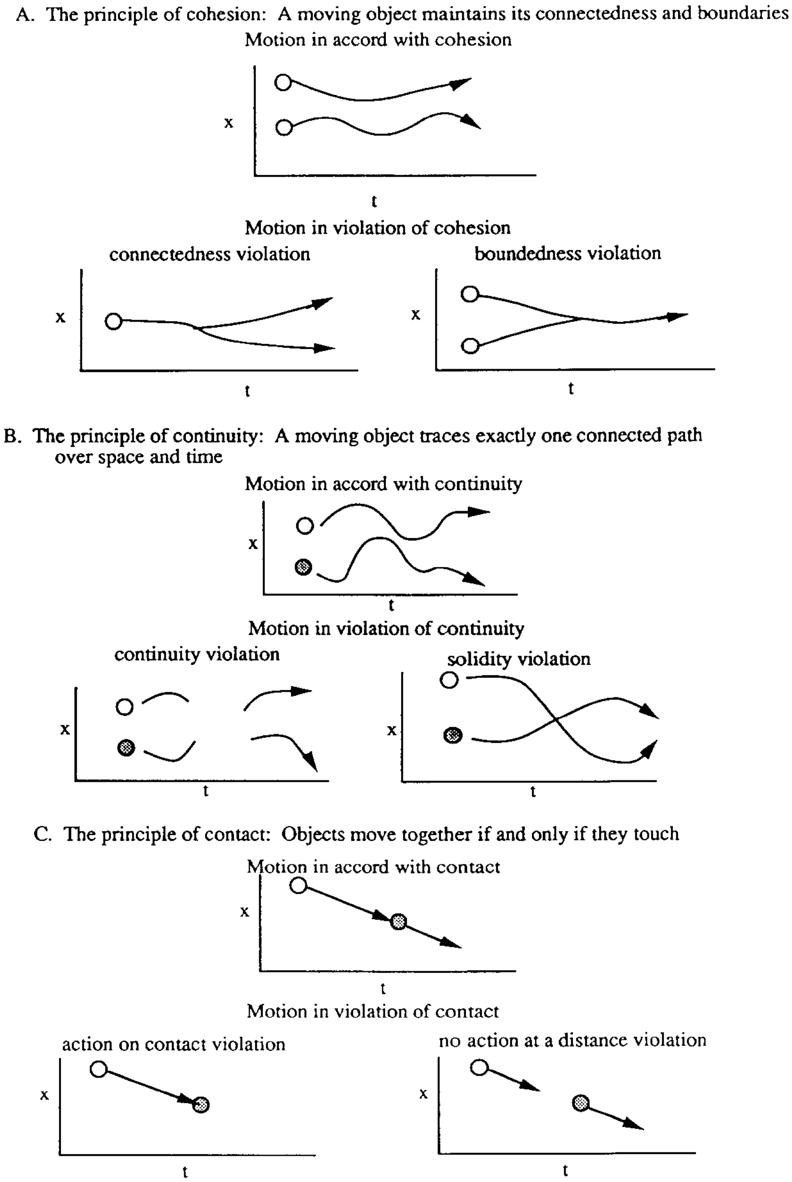

Fig. 2. *Principles guiding infants' physical reasoning and the constraints they encompass. Each line depicts the path of an object over one-dimensional space and time.*

do not appear to guide early reasoning in the domains of number, geometry, or psychology. For example, the cohesion principle does not guide early reasoning about number: The youngest children who have been studied appear to appreciate that a set can be composed of unconnected objects (Wynn, 1992; see also

Gelman & Gallistel, 1978). The continuity principle similarly fails to guide early reasoning about geometry: young children appreciate that two lines can intersect such that both occupy the same point at the same time (Silberstein & Spelke, 1992). Finally, the contact principle does not guide early reasoning about persons: infants appreciate that one person can affect another person's actions by interacting with that person at a distance (Woodward, Phillips, & Spelke, 1993). These studies and many others (see especially Carey & Gelman, 1991; Gallistel, 1990; Hirschfeld & Gelman, 1994) suggest that multiple, distinct systems of knowledge underlie initial reasoning.

4. Initial knowledge encompasses fundamental constraints on the entities in a domain

Most of our mature knowledge does not appear to be shared by infants. For example, young infants may not appreciate that falling objects tend to fall to a supporting surface (Spelke, Breinlinger, Macomber, & Jacobson, 1992), that people tend to act on the things at which they are looking (Spelke, Phillips, & Woodward, in press), or that visible objects can mark the child's position and orientation (Acredolo, 1978; Hermer, 1993). Comparing the knowledge that infants possess with the knowledge that they appear to lack suggests this generalization: initial knowledge encompasses the most reliable constraints on objects, people, sets, and places that humans recognize as adults.

Two examples illustrate this suggestion. In our studies, young infants appear to reason about physical objects in accord with the principle of continuity but not in accord with the principles of inertia (objects move smoothly in the absence of obstacles) or gravity (objects more downward in the absence of support (Spelke et al., 1992; Spelke, Katz, Purcell, Ehrlich, & Breinlinger, in press) (see Fig. 3). These findings were not expected, because evidence for the effects of gravity and inertia is ubiquitous in infants' perceptual and sensorimotor experience, whereas evidence for continuity appears more subtle (see Spelke et al., 1992, for discussion). Because objects enter and leave the field of view with every movement of the eyes, an object's uninterrupted existence and continuous path of motion could only be discovered through elaborate and extended investigations of the perceptual world (Piaget, 1954). If the principle of continuity is not perceptually obvious, however, it is deeply true. At the level of middle-sized, perceptible objects, this principle applies without exception: no material object can exist or move discontinuously. In contrast, the more obvious constraints of gravity and inertia are not as reliable: material objects do not always move downward in the absence of perceptible support or move smoothly in the absence of perceptible forces.

The second example comes from Linda Hermer's studies of geometrical

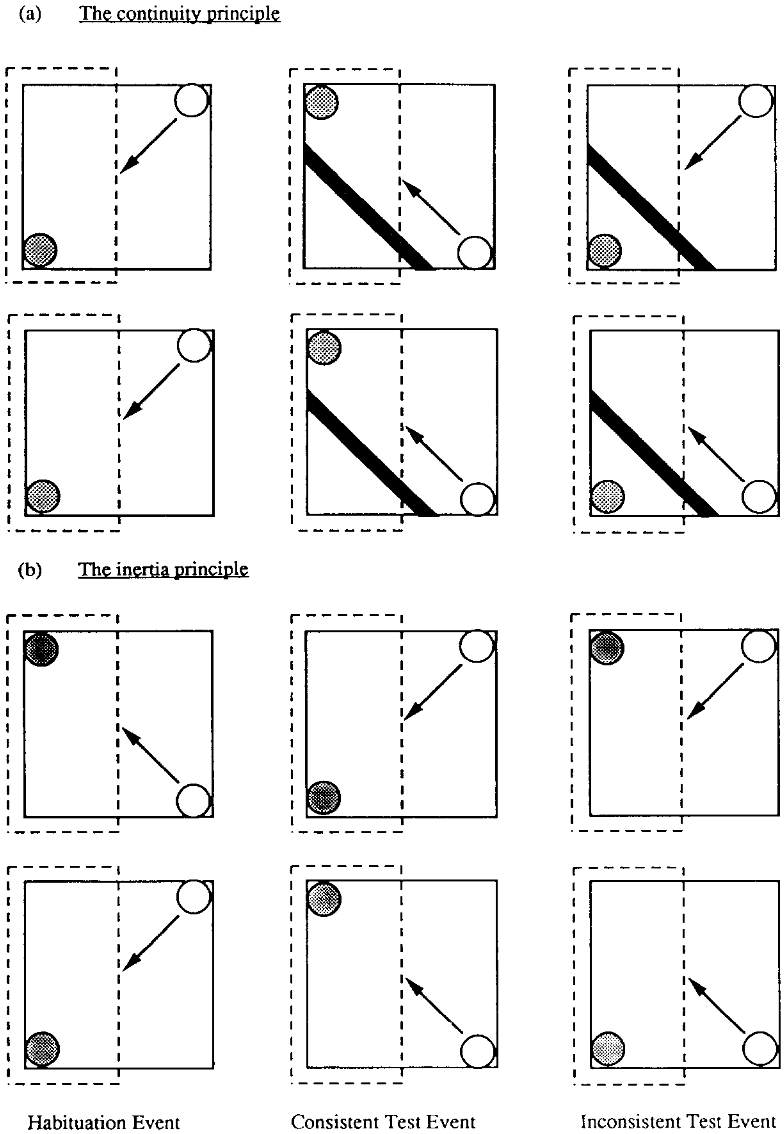

Fig. 3. *Overhead view of displays for (a) a study of infants' knowledge of the continuity principle, and (b) a study of infants' knowledge of the inertia principle. Arrows indicate the path of visible object motion. Dotted lines indicate the position of the occluder. An open circle indicates the object's position at the start of an event. After the object moved behind the occluder, the occluder was removed, the object reappeared at rest at the position of the shaded circle, and looking time began to be recorded. When looking times to the consistent and inconsistent event outcome displays were compared, 6-month-old infants showed a reliable preference for the event outcome that was inconsistent with the continuity principle. In contrast, 6-month-old infants showed no preference for the event outcome that was inconsistent with the inertia principle and tended to show the opposite preference: longer looking at the superficially more novel, consistent outcome (after Spelke et al., in press).*

reasoning (Hermer, 1993). Following research with rats (Cheng, 1986), Hermer studied young children's ability to reorient themselves and locate a hidden object after they had lost their sense of their own position and heading. In this task, the object's position and the child's orientation could be determined only in relation to perceptible features of the environment that were observed by children both before and after they were disoriented (see Fig. 4). At the youngest ages tested, children reoriented themselves and located the object by analyzing the shape of their surroundings: For example, they identified the object's location as a corner of the rectangular room whose longer side was on the left rather than on the right. In contrast to adults, young children did not use non-geometric features of the layout such as the color of a wall or the identity of a movable landmark to reorient themselves or to locate the object: for example, children did not identify the object's location as a corner that was blue and white rather than entirely white, or as a corner that was close to a toy truck rather than a toy bear. When young children reorient themselves, they appear to be guided by the constraint that the permanent spatial layout maintains a constant form, but not by constraints that the layout is constant in color or texture or is furnished with objects at constant locations.

Hermer's finding that children ignore perceptually salient aspects of the layout and orient in accord with the geometry of the layout is striking, given that young children can use non-geometric properties of the layout such as surface coloring to guide a variety of object-directed actions (e.g., Bremner, 1978). According to Gallistel's (1990) analysis of orientation and spatial representation, however, only the geometry of the layout provides highly reliable information about the location of the self or of other objects: the ground may change from green to white and object landmarks may be kicked or blown around, but the shape and location of a cave or mountain is extremely unlikely to change from one encounter to the next. (Emlen, 1975, offers an analogous observation concerning avian celestial naviga-

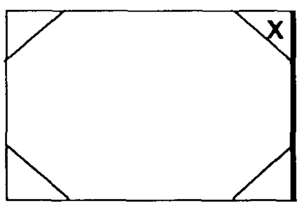

Fig. 4. *Overhead view of an apparatus for a study of young children's spatial reasoning. The "x" indicates the position of the hidden object; the dark line indicates the position of the single blue wall. After children were disoriented, they searched with equal frequency at the blue and white corner containing the object and the geometrically equivalent, all-white corner that was opposite to it. Children searched at these two corners reliably more than they searched at the corners that were adjacent to the object's hiding place, indicating a sensitivity to the geometric information that specified the object's location (after Hermer, 1993).*

tion). In Hermer's research, young children's geometric reasoning is guided only by the most reliable information.

The suggestion that initial knowledge encompasses the most reliable constraints on the entities in a domain of reasoning is not trivial or self-evident, and it is not true of children's later-developing knowledge. When children first begin to reason about plants, cooking, or kinship, for example, they fail to capture fundamental properties of the entities in these domains and focus instead on the most perceptually obvious properties (Keil, 1989). Children are apt to learn that plants are green before they learn that plants take in nutrients, grow, and reproduce (Carey, 1985), and to learn that grandmothers are old and sparkly eyed before they learn that grandmothers are the mothers of parents (Keil, 1989; Landau, 1982). Like the fundamental constraints on plants and grandparents, the fundamental constraints on objects, human agents, sets, and places are not the constraints that are most perceptually obvious. Indeed, some fundamental constraints (e.g., that human action is intentional, that every number has a successor, and that one and only one line connects any two points) cannot be perceived at all. Unlike later-developing knowledge, initial knowledge appears to capture what is most true about the entities that a child perceives, not what is most obvious about those entities (see Kellman, 1993, and Wellman & Gelman, 1992, for further discussion).

5. Initial knowledge is innate

There surely is a time in human development, prenatal if not postnatal, when human beings know nothing. What causes the transition to a state of initial knowledge? The most popular answer to this question is "experience", both perceiving and acting on the environment. Studies of early cognitive development do not refute this answer, but I believe they cast doubt on it for a number of reasons. One set of reasons follows directly from the above considerations: if early knowledge encompasses environmental constraints that are not obvious in the child's perceptual and motor experience while failing to encompass more obvious constraints, then this knowledge is not likely to have been shaped by the child's perceptual and motor experience. If the constraints are highly reliable, moreover, then natural selection may have favored the evolution of mechanisms that give rise to this knowledge (Kellman, 1993).

A different reason for doubting that initial knowledge is learned follows from a consideration of the problem of perceiving the entities about which one reasons. If children are endowed with abilities to perceive objects, persons, sets, and places, then they may use their perceptual experience to learn about the properties and behavior of such entities. By observing objects that lose their support and fall, children may learn that unsupported objects fall; by observing people who move in the direction they are facing, children may learn that people look at the things they approach. It is far from clear how children could learn anything about the entities in a domain, however, if they could not single out those entities in their surroundings. For example, if children could not represent the object-that-loses-its-support as the *same object* as the object-that-falls (and as a different object from the support itself), they might learn only that events in which something loses support are followed by events in which something falls (the object) and something remains at rest (the support). If children could not differentiate a person from an inanimate object, they might learn only that some things look where they move and other things do not. Learning systems require perceptual systems that parse the world appropriately; this requirement has been discussed at length in the field of perception (Koffka, 1935; Kohler, 1947) and elsewhere (e.g., Pinker & Prince, 1988).

How do infants single out objects, persons, sets, and places as the entities to which their initial principles of physics, psychology, number, and geometry apply? The evidence suggests that in the case of physics the principles that underlie infants' reasoning about objects also underlie infants' perception of objects (Spelke, 1991; Spelke & Van de Walle, 1993): infants perceive objects by grouping together the perceived surface layout into entities that are cohesive, continuous, and movable on contact. Some evidence suggests that a common set of principles underlies both perception and reasoning about persons, sets, and places as well (see Carey & Spelke, 1994). If the same initial principles underlie perception and reasoning, however, then the principles could not be learned, because the child would have no other way to parse the stream of experience into the relevant entities. Initial knowledge may emerge through maturation or be triggered by experience, by learning processes do not appear to shape it.

6. Initial knowledge constitutes the core of mature knowledge

What happens to initial knowledge over the course of development? Studies in the history of science (e.g., Kitcher, 1988; Kuhn, 1977) and in science education (e.g., Carey, 1988, 1991; Wiser, 1992) suggest that initial knowledge can be displaced, revised, and overturned as new knowledge is acquired. I suggest, in contrast, that initial knowledge is central to common-sense reasoning throughout development. Intuitive knowledge of physical objects, people, sets, and places develops by enrichment around a constant core, such that the knowledge guiding infants' earliest reasoning stands at the center of the knowledge guiding the intuitive reasoning of older children and adults.

The simplest argument for the core knowledge thesis appeals to our intuitions about the necessary properties of material objects, people, sets, and places. For something to be a material object, it must occupy space, displace other things on contact, and cohere as a unit; we do not consider a dimensionless point, a shadow, or the collection of dust floating about a room to be one material body. For something to be a person, it must choose its actions; we do not extend personhood to entities whose motions are caused entirely by external forces. In the domain of number, the principles to one-to-one correspondence and succession appear both to guide children's earliest reasoning and to constitute the core of adults' conceptions (Gelman & Gallistel, 1978; Gallistel & Gelman, 1992). In the domain of spatial reasoning, the principles of Euclidean geometry that appear to underlie the spatial reasoning of human infants and of a variety of non-human species (e.g., Gallistel, 1990) also appear to capture adults' clearest geometrical intuitions.

For those who doubt these intuitions (and the list of doubters is extensive), there are other reasons to believe that initial knowledge will stand at the core of mature common-sense knowledge. One might be called Kellman's reason (after Kellman, 1993). If initial conceptions capture the most reliable constraints on the entities in a domain, then all the child's subsequent perceptual experiences will tend to confirm the initial conceptions. For example, we do not unlearn the principle that objects exist continuously, because no perceptible material objects violate this principle. A second might be called Kohler's reason (after Kohler, 1947). If initial knowledge serves to define the entities in a domain for the child-learner, then things that fail to conform to the initial conceptions will not be picked out as entities in the domain, and so their behavior will not undermine those conceptions. For example, we do not unlearn the principle that persons choose their actions, because any apparent counterexample to this principle is excluded from the class of persons: presented with something that looks, smells, and sounds like a person but whose movements are caused by a machine, we do not conclude that the entity is a person and that some people do not choose their actions, but rather that the entity is a robot.

A third reason to believe that initial knowledge constitutes the core of mature knowledge might be called Kuhn's reason (with apologies to Kuhn, who will not endorse these arguments). Human cognition is conservative: people strongly resist changing their central conceptions. Rather than give up a set of beliefs that are central to us, we will ignore, explain away, or even misperceive contrary evidence (see Karmiloff-Smith & Inhelder, 1974/75). As a consequence, radical conceptual changes are rare even in the history of science and in science education, where they are most often remarked upon. When conceptual revolutions occur, moreover, they are accompanied by cognitive and social upheavals that seem quite different in quality from the apparently effortless processes by which people gain an intuitive grasp of their surroundings. These considerations suggest that ordinary cognitive development resembles what Kuhn (1962) called "normal science" – a process of enrichment around constant core principles.

If initial conceptions are constant over the spontaneous development of common-sense knowledge, then they also are universal across human cultures and historical times. They are a body of knowledge that all humans share, whatever the diversity of our elaborated belief systems. Studies of this core can provide anchor points for studies of cultural diversity (see Hirschfeld & Gelman, 1994; Premack, Premack & Sperber, in press). More important, an appreciation of this core can serve as a starting point for anyone who still hopes, current appearances to the contrary, that people in different social circumstances, with different histories, traditions, and religions, might nevertheless be able to understand one another.

7. Initial knowledge is task specific

Is there a single system of knowledge guiding all our reasoning within a given domain? Recent research on infants' reasoning about object motion suggests not: there is a discrepancy between the constraints on object motion that guide young infants' inferences about the positions and motions of objects when infants observe physical events without acting upon them, and the constraints that guide young infants' inferences when the objects are in reach and infants attempt to catch them.

Young infants reach predictively for moving objects: they extrapolate an object's motion so as to intercept it ahead of its currently perceived position (Hofsten, 1983). Recent studies have investigated the constraints on object motion that guide these extrapolations. Because young infants' inferences about object motion appear to be guided by the continuity principle but not by the principle of inertia, the studies of predictive reaching focused on those principles. Six-month-old infants were presented with an object that moved within reaching distance on four different paths: two linear and two non-linear paths that intersected at the center of the display, just out of the baby's reach (Fig. 5). In two studies, the object's motion was fully visible, and reaching was found to accord with the inertia principle: as the object moved through the center of the display, infants aimed for a position further along the line of its motion (Hofsten, Spelke, Vishton, & Feng, 1993). In further studies, a small occluder covered the display's center, and reaching was found to be disrupted: infants attempted to reach less frequently, and reaches that were initiated before the object was hidden rarely were sustained over the period of occlusion (Hofsten, Spelke, Feng, & Vishton, 1994). These results are exactly opposite to the findings of studies of 6-month-old infants' inferences about the motions of hidden objects in situations in which infants observe objects but do not act upon them. Separate systems of knowledge appear to guide infants' reasoning about objects in these two situations.

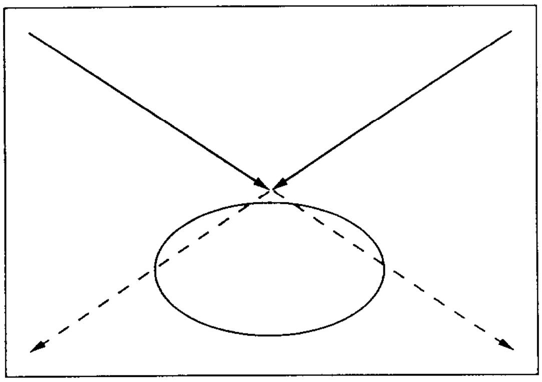

Fig. 5. *Displays for a study of infants' predictive reaching for linearly versus non-linearly moving objects. Solid arrows indicate the paths of motion up to the center of the display; dashed arrows indicate the paths of motion after that point; a circle indicates the optimal area for reaching for the object (after Hofsten et al., 1993).*

Adults and older children may also draw on separate knowledge systems when they act on and reason about objects. A child who launches an object on a sling may extrapolate the object's motion on a linear path, for example, while judging that the object will follow a curvilinear path (Krist, Fieberg, & Wilkening, 1993; Piaget, 1976; but see also McCloskey & Kohl, 1983). Nevertheless, adults and older children appear to integrate distinct knowledge systems under conditions in which infants fail to do so. From the age of 18 months, children search for hidden objects only in places to which an object could have moved by tracing a connected, unobstructed path (Piaget, 1954). Developmental changes in object search therefore suggest that knowledge of physical objects undergoes a change between infancy and adulthood. Although the same domain-specific and task-specific systems may guide human reasoning at all ages, these systems may become increasingly interactive as children grow (Karmiloff-Smith, 1992; Rozin, 1976).

The increasing interactions among distinct systems of knowledge may have further consequences for children's thinking: children may extend their reasoning about the entities in one domain by bringing to bear their knowledge of entities in a different domain. For example, children's psychological concepts may begin to support reasoning about physical phenomena (Boyer, 1994) and the reverse (Gentner & Grudin, 1985), children's concepts of number may come to support reasoning about object weight and density (Carey, 1991), and children's geometrical concepts may enable them to reason in new ways about number (Gelman, 1990). Science often depends on linkages across distinct domains of knowledge, creating such disciplines as analytical geometry, mathematical physics, and mechanistic psychology (see Carey & Spelke, 1994). The ability to make these linkages, in turn, may depend on the increasing interactiveness of domain-specific and task-specific systems of knowledge.

8. Conclusions

A picture of cognitive development emerges from studies of initial knowledge. Humans are endowed with a number of systems of knowledge, each consisting of a limited set of principles capturing highly reliable constraints on a significant class of entities. Over the course of human development, each system of knowledge grows as the principles at its core are enriched by further, generally less reliable notions. In addition, distinct systems of knowledge come to guide an increasingly wide range of actions and come to be related to one another. Although studies of early development have not revealed the processes that enable children and adults to link distinct knowledge systems to one another and to systems guiding action, they suggest situations within which psychologists may begin to study these processes. Studies of these processes, in turn, may shed light on an aspect of cognition that is perhaps unique to humans: our ability to extend our systems of knowledge into territory that lies beyond their initial bounds.

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