Early Foundations of Cognitive Development

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For much of this century, most experimental and developmental psychologists assumed infants could not form abstract concepts. This prevailing view followed from two assumptions: (1) that the newborn mind is a blank slate upon which the record of sensory experience is gradually impressed, and (2) that language is an obvious prerequisite for any abstract thought. With the development of methods to study the minds of infants have come a barrage of findings that call into question these core assumptions. Consider but two.

Piaget highlighted the difficulty infants have with concealed objects. For example, when four-to-eight-month-old infants 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 same object disappears behind a barrier. Piaget took this pattern of behavior to mean that objects out of young infants' sight were also out of their mind, existing only so long as they were perceived. This interpretation is challenged by studies done by Renée Baillargeon (University of Illinois), Phillip Kellman (Swarthmore College), Elizabeth Spelke (University of Pennsylvania), and their colleagues.

These investigators' studies often take advantage of the fact that infants will look at an interesting or novel display until they are bored, at which point they are habituated to that stimulus and look away. The presentation of another stimulus often leads to their renewed interest—or what is called recovery from habituation. In one study,[1] five-month-old

babies watched a screen repeat y rotate toward and
away from them, passing th ugh a 180° arc, as
would a page turned back anc rth in a book lying
open on a table. When the ba s' interest in look-
ing at the rotating screen h tuated, they were
shown a yellow cube, placed t ne side of the same
screen (now stopped in an up it position). While
the infants watched, the cube moved behind the
screen, and the crucial part c ne experiment be-
gan. Infants once again saw screen rotate: on
alternate trials it rotated thro a full 180° arc and
thus, from an adult's point of w, seemed first to
crush and then to regenerate tl object; on the other
trials they saw the screen rot through the 120°
arc that it should have, given t solid object behind
it. (One-way mirrors and va d lighting accom-
plished the visual effects neec to produce the im-
possible event generated by e 180° rotation.)
Although the infants had pre asly habituated to
the full rather than the p al rotation, they
nonetheless looked longer at t full rotation, treat-
ing the habituated event as mo novel than the one
they had never seen. To treat t exact same visual
display they had habituated t s a novel one, they
must have *thought* it was *not* t same event. They
must have assumed that a sol object was behind
the screen and that two objec cannot occupy the
same space. Their failure to r rch for hidden ob-
jects, then, cannot be taken as dence that objects
exist for them only as long as y themselves per-
ceive them.

Another demonstration tl infants can and do
form abstract representations mes from studies
by Starkey, Spelke, and Gelma n infants' abilities
to respond to numerically rel nt information. In
one study, six-to-nine-month-c nfants were habit-
uated to color photographs o ther two or three
assorted common househo items—a sponge,
cloth, vase, comb, apple, etc. (h trial displayed a
different set). Infants who we habituated to two-
object displays then looked ger at three-item
ones, and vice versa. In a furt study (illustrated
in Figure 1), infants also demc rated an ability to
abstract numerical informat presented in two
different modalities. They ha reliable tendency
to look longer at the one c wo displays that
matched the number of drur ats (two or three)
they heard emanating from a c trally placed loud-
speaker.

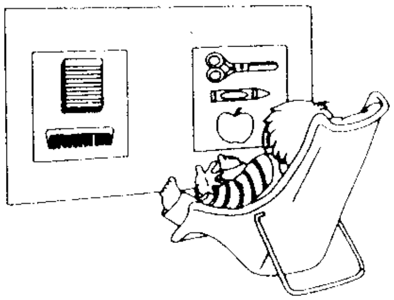

FIGURE 1
Schema of the method used to determine whether six-to-eight-month-old infants respond intermodally to numerical information. In a series of studies, babies were sat either on their mother's lap or in an infant seat and shown pairs of slides, one displaying three objects, the other two objects. The objects in the slides varied from trial to trial, and on each trial the infants heard either two or three drumbeats emanating from a hidden, centrally placed speaker. The infants showed a reliable tendency to look preferentially at the visual display in which the number of items matched the number of drumbeats played during a trial, thus demonstrating an ability to abstract number across item types and modalities. See P. Starkey, E. S. Spelke, & R. Gelman, "Numerical abstraction by human infants." *Cognition* (in press)

Results like these led us and our colleagues in the Center's 1984–85 Special Project on Structural Constraints on Cognitive Development, Susan Carey and Frank Keil, to consider the proposition that infants are born with both some principled knowledge in some domains and a predisposition to participate actively in their own cognitive development.

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Implicit Principles Guide Learning

In this essay we take the assumption that infants come to the world with some domain-specific principles of knowledge as one of our starting points.[2] We do not, however, presume that infants are born with well-worked-out theories about numbers, the kinds of objects there are in the world, or the way objects interact with one another. We want to grant infants just enough competence to account for what they eventually learn in these domains. We believe the function of the competence infants are born with is to guide and facilitate subsequent learning, and that without some initial competence, such learning would be more difficult if not impossible. How might initial principles support learning? Before answering that question we must consider just what might be the implicit assumptions or principles infants are endowed with. We start with the domain of objects.

Principles for Learning about Objects

Spelke suggests that infants begin with the assumption that their environment is three-dimensional and composed of things that occupy space, persist, move as units independently of one another, and maintain their coherence and boundaries as they move. Two principles of object perception follow: two surfaces will be perceived as part of the same object if they touch each other; and two surfaces that move together at the same time and speed along parallel paths in three-dimensional space—even if their connection is concealed—will be perceived as surfaces of a single object. Together these principles would allow infants to learn which surfaces of a partially concealed or nonconcealed object belong together. (To appreciate the depth of the problem of concealed or occluded objects, ponder the clutter on the typical faculty desk and our conviction that the underlying desk, nevertheless, has a continuous surface.)

Note that these principles say nothing about infants' sensitivity to color, size, shape, etc., the kinds of attributes that figure centrally in the associationists' account of how infants come to know objects. In other words, these principles contrast with ones that have infants gradually building up a notion of the object by learning to associate the particular sensations generated by different objects. By that account obje that share a common color or substance, for e mple, generate sensations that are most likely e associated. The ability to find an object, even hen it is partially occluded, then would deriv om common or similar sensory associations. Se lke's account does not deny infants the ability t erceive these attributes; rather it maintains th sensations produced by these attributes are no ed when infants first sort the environment int ifferent objects. Her account allows infants to tre objects with different colors and textures on each arface as one and the same object and to do so with much ease as with any other continuously bo ded or tandemly moving surfaces. It also explains y infants and adults treat some objects, e.g., a s ceboat, as one, when their components are co ected, and others, e.g., a cup and saucer, as tw when the exact same parts are not connected. S lke's principles also account for the possibly apo phal story regarding the Incas' initial assump s about the kind of creature they were seeing en they first encountered Spaniards on horses. L end has it that they assumed man-plus-horse w a new, exotic beast—until they saw the never-be re-seen Spaniards dismount from their never-b re-seen horses.[3]

So, it is n hat infants learn nothing about the color and sha e of particular objects. Rather, it is that they fir pick out the objects on the basis of the two princ es of object perception given above, and then lea details about them. A related argument can be de for the way children learn about different kin of animate and inanimate objects. Gelman and r colleagues argue that a sensitivity to the source an object's movement, in conjunction with th bility to respond to information about the wa ojects move and change state, makes it possible fo nfants to learn to sort objects into what adults k w to be animate and inanimate categories. If we ant the young such principles for organizing ol ts, we can account for Keil's finding that the abili o distinguish between animate and inanimate ob ts is the first ontological distinction made by you children. Thus, for example, he has shown that e preschool children deny that a door can be sorry, d, or hungry, but agree that it is all right to say h things about people.

Given th ncipled concern for the cause of an object's mov ent and an ability to assign the

source of the movement to something either inside or outside an object, there are other kinds of learning that we would expect to follow with relative ease. Young children might readily learn that the insides of animate and inanimate objects are very different, and that attributions to animate objects of other nonvisible characteristics are legitimate. The fact that three-to-five-year-old children often say people but not dolls have stomachs, or that people and cats remember but dolls and puppets do not, fits this analysis. Note, once again, that perceptual similarity does not predict these response patterns. Dolls and puppets can be said to look at least as much like people as cats do.

It is one thing to learn that statements with motivational and biological predicates refer to animate but not inanimate objects. It is quite another thing to understand these predicates and then use them correctly. Indeed, Carey's work highlights how little young children understand about the biological theory that contributes to older children's and adults' understanding of why invertebrates and vertebrates are all animals, even though many of them bear little, if any, resemblance to human beings.

The implication of the foregoing is that we should expect young children to believe that all animate objects can move themselves, but not to know how they do it or why they eat or how generations are related to one another. We might also expect young children to learn rapidly that intentional and mental expressions refer to something inside their bodies but still to know little of what these mean. In the absence of a theory of psychology and biology, young children could even assume that such "insides" are physical objects and hence have weight. This is exactly what Keil found. His five-year-old subjects contended that "ideas are heavy." Clearly then, to say the infant has some principled knowledge about the difference between animate and inanimate objects is not to say they know all. They must first learn enough facts to make it possible to organize these into the coherent theories Carey describes for older children.

The idea we advance here, then, is that infants are born with implicit principles about objects and the perceptual abilities necessary for them to learn which surfaces go together and which objects do and do not cause themselves to move. These abilities then support further learning about objects. In the case of the animate-inanimate distinction, they constrain the child to learn the right class of things about objects. They do not, however, tell the child what to think about particular objects. If they did, there would be something wrong with our theory. For although man has always differentiated between animate and inanimate objects, his theories about these have changed many a time. These theories need not even be consistent with one another (see Toulmin and Goodfield for an illuminating discussion of this point).[4]

Principles for Learning about Number

Children have to learn the count words (one, two, three . . .) when counting objects. Some might say this is a trivial problem; after all, the environment of the child is permeated with examples of the count words. Perhaps, but the same is true for color words. Yet preschool children have a much easier time learning to use their first number words than their first color words. The fact that something is in the environment does not guarantee that it will be noticed, let alone learned. There has to be a reason to attend to the information. Further, in the absence of a framework within which to interpret that information, it is much harder to assimilate it. If we grant young children some implicit principles or an interpretive framework for number, we achieve both an account of why the count words are attended to and why some of them are used correctly at an early age.

Gelman and her colleagues note that the ability to count in order to achieve a cardinal representation of the numerosity of a set—i.e., to know after counting four objects that the number four represents the whole set—is governed by five principles. The first three, the how-to-count principles, are: (1) the one-one principle—each item in a collection must be uniquely tagged; (2) the stable-order principle—the tags used must be drawn from a stably ordered list; and (3) the cardinal principle—the last tag used has a special status; it unlike any other tag can represent the cardinal value of the set. Whereas these principles serve as constraints—if they are not applied the behavior is not counting—the next two do not. Just as Spelke's principles have implications for the kinds of things children will not take as critical, so do the how-to-count principles. In particular, note the absence of any statement about the kinds of items that can be collected together for the purpose of counting. To capture the indifference of counting to item type, Gelman proposes (4) the abstraction principle—it matters not what kinds of items or events, real or imaginary, are collected together for counting. Finally, whereas the how-to-count principles require that the numerical tags be stably ordered, they do not require that the spatial arrangement of the items be similarly ordered. Hence, counting principle 5 is the order-irrelevance principle—the order in which the items themselves are counted is irrelevant.

There is evidence to justify granting preschoolers implicit understanding of these five counting principles, as well as the arithmetic ones that addition and subtraction change the value of sets. It is not clear how many of these principles should be granted infants. That babies abstract number across the auditory and visual modalities suggests the abstraction principle is part of their initial competence. And since the most straightforward account of their intermodal ability involves postulating an early form of one-to-one correspondence matching, at least some aspects of the one-one principle are also a candidate component of their initial competence. Finally, very young counters sometimes use their own idiosyncratic versions of the standard count list. This indicates they bring the stable-order principle to the language-learning task, a principle that focuses their attention on lists that occur in the environment in a reproducible order.

Consider the child who counted "one, two, seven . . . ," answered "two" when asked how old he was, and "seven" when asked how old he would be on his next birthday. This boy used his own list to tag events—in this case birthdays—and did so in full accord with the requirements of the how-to-count principles. That his list was not conventional bears tellingly on the question of whether the stable-order principle guides development or is inferred following rote learning of a conventional list. Surely he did not hear others use his count list.

If we allow that the stable-order principle functions as a principle in search of lists suitable for counting, we have part of the explanation for young children's frequently demonstrated ability to interpret correctly a very ambiguous environment. To illustrate the problem, consider the following hypothetical case. A father is in the habit of reading to his preverbal child from one of the many books that have pictures of many different objects on each page. On one day he points to each object in turn and says "cow, bus[illegible]ar, dress, banana." On another day, he points to the same objects and says "brown, green, red, pink, yellow." On yet another day, he says "one, two, three, four, five." Picking up another book, he points and says "house, pig, sun, bike, coat," then "white, p[illegible], orange, red, and green," and finally "one, two, three, four, five." Notice that with both the count words and the color words, the same terms were used more than once. In contrast, each identifying label was used but once and only for a single kind of object. Also notice that each object was "labeled" with three different terms, a standard label, a color term, and a number word. Given all this, on *a strict associationist account*, one might expect that children would either learn three names for each object or learn to use only those names that are assigned uniquely. Further, since every number word was paired with two different objects, children should have the hardest time learning how to use these.

But recall that young children will be predisposed to treat words that occur in stably ordered lists as terms to which the counting principles are applicable. It follows that they should assume that ordered sets of tags that are applied in one-to-one correspondence with objects in arbitrary collections can be used with any set of objects (the abstraction principle). This assumption precludes their thinking that words in a count list are names for any particular objects—especially since we know they also have assumptions about the way labels for objects are supposed to behave. Soja, Carey, and Spelke report that beginning language learners assume a novel label refers to an object as a whole and not to the material from which it is made. And Ellen Markman (Stanford University) finds that young children are constrained by the mutual exclusivity principle—each object must have one and only one unique label. Principles for naming and principles for counting, then, help young children make sense of what would otherwise be a very confusing verbal environment. The [illegible]lso may be the source of the young child's trouble in learning color terms. The use of such terms violates Markman's mutual exclusivity principle and Spelke's rule that objects (as opposed to their parts or attributes) have naming priority.

Again, we must emphasize that principles may help get learning in a domain off the ground, but they will not guarantee that the subsequent learning is done with facility. In the case of the count words, children, like adults, face the difficult task of learning a long list. It is a well-known fact about human memory that such learning is very difficult. To get around the problem, we typically learn to chunk a list into meaningful units. In English (and many other languages), unfortunately, young children have to learn the count words up to at least twenty-two or twenty-three before they can even begin to get information about the rules that organize the generation of the list. So they may know that they have to use the count words when counting and yet have trouble counting because they have to master a long list by rote.

When children do not have to depend on rote learning to acquire knowledge about number and can instead assimilate the environment to an already available principle, they learn at least some things with considerable ease. The general proposition is that available knowledge in a domain facilitates further learning within that same domain. The following example illustrates this proposition and provides clues as to the way new principles are learned.

Acquiring New Knowledge in the Number Domain

To develop this example, we turn to an experiment done to assess preschoolers' understanding of the order-irrelevance counting principle. Three- and four-year-old children were asked to count in an unusual way. To start, the experimenter pointed to the second item (a trinket-sized baby doll) in a row of objects and asked the child if she could count the objects so that the "baby" was "the one." Having done this, the child was asked to make the "baby" "the two," then "the three," etc. To succeed at this task, children must devise novel solutions; they cannot simply count from one end of the display to the other. The kinds of solutions children produce are many, including skipping around as they count items, or rearranging the position of the items in the display. An example of the skip-around solution was observed on a trial where one child had to make the second item be "the three." She started counting with the first item, skipped to the third and tagged it "two," returned to the second and tagged it "three," skipped to the fourth and continued to count. An example of the rearrange solution occurred in response to the same request to another child, to make the second item be "the three." He took the second and third items in the row and switched their positions. Then he could and did count from left to right. Such solutions reveal the child's facility with the order-irrelevance principle.

Of interest for the present discussion is that the rearrangement solution also reflects principled knowledge that is not included in the five counting principles set forth earlier. These principles offer no guidance on using the counting tags to represent the spatial positions (e.g., third or fourth in a row) of items in an array. The ordinal principle (6) does—an object in a spatially ordered array can be said to be in the *n*th position when the count-procedure *is* order-preserving. Thus, although it is true that tagging order is irrelevant with respect to the cardinal value of the whole set, it is not irrelevant with respect to the ordinal number word that indexes an item's spatial position. Could children have learned this, and hence a new principle, given the availability of the first five principles? Or do we have to modify our account of early competence and add the ordinal principle to its characterization? We can avoid the second course if we assume that young children learn most readily when they create or encounter structural isomorphs.

Although one need not arrange objects in a row to count them, there is a processing advantage to doing so. Recall that the one-one principle dictates that each object must be assigned one and only one unique tag. Hence, anyone counting an array of objects has to keep track of those that have already been tagged and separate them from those yet to be tagged. If objects are scattered all over the place, the chances are that the counter will lose track of just which ones have already been tagged. If the objects are arranged in a row, by contrast, keeping track simply requires moving on in the same direction. All this points to a sound reason for children and adults to prefer to count objects in a row and to adopt this as the conventional mode of counting. But notice what happens as a result. The child is presented case after case of a structural isomorph between the nonnumerical spatial order of objects and the numerical order of the count words—just the kind of input we propose below as most likely to facilitate transfer or new learning. Of course, this account would not work if children did not already have some implicit principled knowledge about counting and did not participate actively in their own learning. In the next section we develop the themes that young children often take control of their learning, are motivated to find structure, and learn rapidly if they can capitalize on structural isomorphs between a principle of knowledge they already have and one in the environment that they create or encounter.

Early Learning: Active and Structure-Seeking

Implicit in the foregoing discussion of learning is the idea that even the very young actively engage their environment, bringing their knowledge to bear on the task of learning what is in it and how to interpret it. This idea that the young participate in their own learning, like the idea that learning is guided by principles, contrasts with what used to be the prevalent view of the young. It does not accord with the characterization of the young as vessels into which we pour gobs of data until they have accumulated enough to start forming representations of objects or concepts. Again, once investigators figured out how to do the necessary studies with very young children, the findings told us otherwise.

Self-Motivated Learning

We now know that even very young children are actively involved in orchestrating their own learning, systematically experimenting and monitoring their own manipulations and observing naturally occurring variations. Central to many current theories of development, notably Piaget's, is the metaphor of the child as a self-directed learner seeking data to support, test, and even modify a current hypothesis. Children learn in situations where there is no obvious guidance, no feedback other than their own satisfaction, and no apparent external pressure to improve or change. They act to some extent like scientists, creating theories-in-action that they challenge, extend, and modify quite on their own. The child is not only problem solver but problem creator, roles much in keeping with (although not identical to) that of the scientist.

Studies of sustained, self-motivated learning have typically been situated within simple problem domains, where rapid learning is possible and it is easy to ma[illegible] progress. DeLoache (University of Illinois) and colleagues, for example, have worked with children's solutions to a variety of stacking problems.[5] Children below 30 months of age beginning such tasks as stacking a set of cups of graduated size often resort to *brute force*; when a large cup is placed on a smaller one, they repeatedly twist, bang, or press down hard on the nonfitting cup. Also favored by younger children is a concentration on *local correction* only; after trying to place two nonfitting cups together, the child tries to find a replacement for only one cup, a minimal restructuring involving the relation between but two cups at a time. A third characteristic ploy of children below 30 months is to *dismantle the entire set* and start again whenever a cup does not fit.

Older children (30–42 months) faced with a nonfitting cup engage in correction procedures that involve *consideration of the entire set* of relations involved. Examples of more sophisticated strategies are *correct insertion*, where the stack is parted at exactly the point that will enable the positioning of a new cup into its correct place, and *reversal*, where two nonfitting cups are immediately reversed into the correct relation.

The rapidly executed reversal and insertion strategies do not occur initially in younger children, who repeatedly assemble, for example, cups 4–1, starting with 4 as a base and then inserting 3, 2, 1. On encountering the largest cup, 5, they attempt to insert it on top of the completed partial stack, pressing and twisting again and again. When brute force fails, they 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 is to begin again.

Over the short period of a few days, however, two-year-old learners progress from piecemeal activities and local fl[illegible] ploys to a dependence on correct insertion and reversal, thus showing a thoughtful consideration of the relations between elements of the whole problem. Two-year-olds in a matter of days come to deal with stacking cups in a manner analogous to that of four-year-olds. Young children left to work on a problem over short periods of time (hours or days) show the same developmental progression from immature to mature activities seen in cross-age descriptions of initial attacks on the problem. This form of learning is widespread, age-independent, and, most important, self-motivated.

The most impressive evidence of self-motivated learning comes from cases where children persistently improve their line of attack even 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 working procedures. In these cases, it is not failure that directs change, but success that the child wishes to refine and extend.

Work done at the University of Geneva by Karmiloff-Smith and Inhelder[6] illustrates this point. Consider, for example, a group of four-to-seven-year-olds who were asked to balance rectangular wooden blocks on a narrow metal rod. These were no ordinary blocks. The *length* blocks shown in Figure 2 have their weight evenly distributed and can therefore be balanced at the geometric center. Some blocks used in the experiment had the weight of each "side" varied either conspicuously (by having a large square block glued to one end of the base rectangular block) or inconspicuously (by having a hidden weight inserted into a cavity on one end); the geometric center rule would not work for weighted blocks.

At first, the children made the blocks balance by *trial and error*. This approach was obviously successful; the children balanced each block in turn; the ostensible goal of block balancing had been reached. This early errorless but unanalyzed phase was spontaneously supplanted by a period of experimentation directed at uncovering the rules gov-

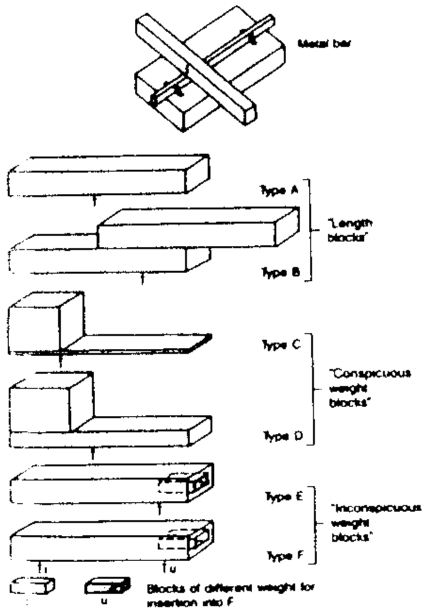

FIGURE 2
Examples of the block types used by Karmiloff-Smith & Inhelder. Children were asked to balance wooden blocks on a narrow metal bar. The "length blocks" had their weight evenly distributed and could be balanced at the geometric center; the "weight blocks" had the weight of each side varied either conspicuously or inconspicuously and could not be balanced at the geometric center. After the children had successfully balanced all the blocks by trial and error, they spontaneously began experimenting to uncover the rules that governed the world of these blocks, beginning with partial theories that accounted for only some of the blocks and persisting until they arrived at a more encompassing theory that accounted for all of them. See A. Karmiloff-Smith & B. Inhelder, "If you want to get ahead, get a theory," *Cognition*, 3 (1974–75), 195–212.

erning balance in the miniature world of these particular blocks. A common early approach was to concentrate on the geometric center and attempt to balance all blocks at that point. This worked only for the length blocks, so weighted blocks were discarded as exceptions ("impossible to balance"), even though the child had previously balanced them all. This uncomfortable state of affairs led to the development of a new, juxtaposed hypothesis, which could accommodate the 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; length blocks were balanced by the geometric center rule and conspicuously weighted blocks by the rule of "estimate weight first and then compensate." Inconspicuously (or invisibly) weighted blocks still generated errors: these blocks looked identical to the length blocks 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 scientists were made uncomfortable by the remaining exceptions and began to seek a rule for them. In so doing, they induced a reorganization that resulted in a single hypothesis for all the blocks. The children paused before balancing any block and roughly assessed the point of balance by balancing each block on their finger. Their comments 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. The child had returned to the point of departure as far as performance was concerned; blocks were balanced without error or the need to designate exceptions. But in the process of self-directed experimentation, a deeper understanding of the rules governing the miniature world in question was developed and tested. In their quest for understanding, the children persisted for long periods of time, often in the face of frustration and even after a functional partial solution had been reached.

Self-imposed pressure to improve adequate partial hypotheses, to produce more encompassing theories, is a critical aspect of scientific reasoning. As is the case ith scientists, it is essential that children first e or develop simple theories that they perfect an ontrol before they entertain more encompassir omplex hypotheses. Karmiloff-Smith and Inhelc refer to this as creative simplification. By ignorin nitially some of the complicating factors, the ch l can begin to construct theories that achieve pa l success. Progress comes only when the inadeq e partial theory is well established and the learner tempts to extend the theory to other phenomen The children or scientists then discover new perties that in turn make it possible to constru ew theories.

New Know ge Should Be in Usable or Structured rm

Another d ng force of learning is the propensity to apply w ever understanding one may have to novel situa s. Controversy surrounding the topic of transfer knowledge is part of the history of learning th ies. Extravagant claims that transfer is omnipre t or, antithetically, that it rarely occurs, have b defended at intervals throughout the century. Co rence can be brought to the data by classifying knowledge to be transferred in terms of its struct l organization and its functional significance t e learner. A failure to make such distinctions responsible for a great deal of controversy. C ider, for example, a continuum of knowledge ctures that spans four points: (1) theory; (2) prin le; (3) isolated rule; and (4) specific solution. If knowledge that is to be transferred is consisten ith or part of a coherent theory or a principled u rstanding, it is nearly impossible to impede a fle e application of that knowledge; we see the work rough the lenses of our preexisting theories or p ciples. If, however, a learner is required to app a previously learned isolated rule or specific solu n, we frequently observe a failure of transfer. It is mmon for fragmentary knowledge to be embedd in one context, a tendency that impedes its appl tion on many occasions where such knowledge c ld be useful but also protects the learner from aive and unwarranted interference.

Transfer i oung children is no exception. As we have seen, y use their emergent naive theories of persons, ol ts, and events to endow novel situations with c rence, but they are hesitant to ap-

ply fragmentary, unassimilated knowledge, which tends to remain embedded within the specific contexts of habitual use. Young children can be seduced into applying even isolated solutions quite broadly, however, by a variety of manipulations that either release the specific solution from its context or encourage the child to form an abstract mental model of the problem structure.

For example, Brown and her colleagues have examined tool use solutions in children of three years of age and older. Consider the following story problem. A Genie, wishing to move his house from one bottle to another, faced the problem of safely transferring a number of precious jewels to the new bottle. The eventual solution is that the Genie commands his magic carpet to roll itself into a tube, places it so as to form a hollow bridge between the two bottles, and then rolls the jewels across the bridge. After listening to such a story, children are presented with problems such as one involving an Easter Rabbit who needs help delivering Easter eggs to both sides of the river. How is the Rabbit to transfer the eggs across the river to his friend in the absence of boats, bridges, the ability to swim, etc.? Conspicuous among the potential solution tools available to the children is a large piece of construction paper that could be rolled into a suitably sized hollow tube. Surprising though it may seem, children do not readily note the problem isomorph and transform the paper into a solution tool.

One method of freeing the solution from context is to manipulate children's prior experience in such a way that they come to see the solution tool (paper, string, stick, etc., depending on the problem) as one having many uses. For example, in the Genie series, children whose prior experience involved using construction paper only as a medium for drawing did very poorly; using the paper exclusively for drawing fixes its function and makes it less available for creative solutions. In contrast, children whose prior experience involved using the paper in a variety of novel ways (as a mask, cover, screen, to construct a toy, etc.) immediately invented bridge solutions for the Rabbit/Genie problems. Experimenting with a variety of uses for the paper frees it from a specific role, transforming it into a tool of many applications.

Also successful at inducing flexible application of a specific solution by three-year-olds are a variety of manipulations that encourage them to create flexible mental models that represent the problems in terms of their common, abstracted goal structure (consisting of the general categories of protagonist, goal, obstacle, solution). Children who spontaneously recall the Genie stories (or are prompted to do so) in terms of a common abstract goal structure transfer flexibly. Similarly, children asked to teach the underlying solution of isomorphic problems to another child also concentrate on the common structure and transfer efficiently, as do children who are required to solve a series of isomorphic problems and thereby develop a mind set to look for analogous solutions. All these manipulations have in common the function of forcing the children to form an abstract representation of the problem situations so that the isomorphism across apparently disparate problems becomes apparent. Once the isomorphism is recognized, transfer is immediate.

The foregoing provides an account of why innate principles of knowledge lead to very rapid learning about phenomena encountered in the environment as well as to the generation of new principles. Children already have available to them the outlines of mental structures that can detect or create structured environments; these environments act as new principles of knowledge that can serve as isomorphs. In the absence of such domain-specific principles, children have first to acquire the principles before they can apply them generally.

Conclusions

Early cognitive development is characterized by the rapid acquisition of certain classes of knowledge. Infants and young children form abstract concepts of objects, numbers, and events from the earliest age that we are able to test them. Furthermore, very young children participate extensively in the structuring of their own learning experiences and are motivated to perfect and apply their new-found knowledge in order to make sense of their world.

The search for structures and the development of these are guiding forces for human learning. We have interpreted these abilities in light of an account of learning and development that grants humans certain domain-specific principles, principles that help infants sort the flow of stimuli they receive and learn about these privileged domains. These principles aid infants in their active search for organized and structured environments. Since learning is facilitated by the presence of knowledge structures, the initial availability of these principles accounts for the rapid learning observed in some domains.

Historically, the study of domain-specific principles that guide the early acquisition of knowledge in privileged domains and the search for general learning principles have been conducted in relative isolation from each other. Future research in cognitive development might benefit from the example of the number domain and consider both aspects of the young child's repertoire, the guiding principles and the learning proclivities that must build on them. A complete picture both of cognitive development in particular and of learning in general will demand this joint focus.

Notes

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1. Reported in R. Baillargeon, E. S. Spelke, & S. Wasserman, "Object permanence in five-month-old infants." *Cognition* (in press).
2. Principles of knowledge are implicit if they underly rule-governed behavior even if they cannot be articulated. Speakers of a language have a principled understanding of some of the constraints on sentences and therefore are able to produce novel utterances and reject as nongrammatical strings of words like "Who did John see Mary and?"
3. Spelke's perceptual principles resemble some of those proposed by Gestalt psychologists—especially the principle of common fate. They differ, however, because they are not taken to underly a gene tendency to look for good form in or to identify objects. Spelke prosee at this tendency, as well as the use o estalt principles like symmetry and g d continuation, are learned. See her p r *Cognition in Infancy*. MIT Occassi l Paper #23, 1983.
4. S. A. lmin & J. Goodfield. *The Architectu of Matter*. Cambridge, Mass.: MIT Press, 1966.
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