Early Foundations of Cognitive Development

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Dunlee at a meeting on November 14th.

For much of this century, most experimental and
developmental psychologists assumed infants could
not form abstract concepts. This prevailing view fol-
lowed from two assumptions: (1) that the newborn
mind is a blank slate upon which the record of sen-
sory 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, these core assumptions con-
siderably were challenged.

Piaget highlighted the difficulty infants have
with concealed objects. For example, when four-
month-old infants are shown an interesting object,
they reach for and grasp it and then allow it to slip
below their visual reach. But they stop reaching or
looking if the same object disappears behind a screen.
Piaget took this pattern of behaviour 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
Renee Baillargeon (University of Illinois), Philip
Kellman (St. John's University), and Elizabeth
Gulick (University of Pennsylvania), and these studies
provide contrary evidence.

These investigations usually 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 move away. The pres-
enence of another stimulus object leads to their renewed interest—what is called recovery
from habituation. In one study, five-month-old
babies watched a screen reveal one object, pass
away from them, and then rotate toward a
second object. The infants watched the cube
screen, and were the observers. Infants once
again were placed in a situation where the
objects were rotated (280°) or not. Most
infants were not surprised by the rotation,
but a few showed some interest in
the rotation. These results suggest
that infants can form abstract concepts and
understand the relationships between
objects.

Results like these led us and our colleagues in the
Center's 1984 Research Project on Structural
Constraints on Cognitive Development, Susan
Carey and Frank Keil, to consider the proposition
that infants are born with both some abstract
knowledge in some domains and a predisposition
to participate actively in their own cognitive de-
velopment.
Implicit Principles Guide Learning

In this case we take the assumption that infants come to the world with some domain-specific principles of knowledge as one of our starting points. 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

Sperling suggests that infants begin with the assumption that their environments are 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 that surfaces of a partially concealed or nonconcealed object belong together. (To appreciate the depth of the problem of concealed or occluded objects, ponder the character on the typical faculty desk and the conviction that the underlying desk, nevertheless, has a continuous surface.)

Note that these principles say nothing about infant's sensitivity to color, size, shape, etc., the kinds of attributes that figure centrally in the associations 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 objects exist, for example, have mass, volume, and object, even would derive associations. So the ability to maintain objects as noninteracting units or trajectories or each to do as with itaneously be explained. As e.g., as the a consistent with connected, are consistent, as the connected, is, possibly spatial assumptions were seeing on horses, plus horned the never be their never before something infants learn nothing about the parts of particular objects. Rather, it is stuck out the objects on the basis of a theory of objects perception given above, details about them. A related argument for the way infants learn about the parts of animate and inanimate objects. Colleagues argue that a sensitivity to an object's movement, in particular the ability to respond to information about the way in which aqueous fluid makes no sense to learn to sort objects into the animate and inanimate categories. The young such principles lead to the idea that the ability to distinguish between animate and inanimate objects is the first ontological distinction children. Thus, for example, he has presented children deny that a door, but agree that it is all right to eat the object's move that share a common color or sub-

ciple. Given the assumptions that animate and inanimate objects are very different, and that attributions to animate objects of other nonanimate characteristics are legitimate. The fact that three to five year old children often say things like not dolls have stomacha, but that people and cats care for dolls and puppets do, flies in the face of this theory. Now, twice, at once, 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 vertebrates do not reflect 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 can or how generations are related one another. We will also expect young children to learn rapidly that intentional and mental representations refer to something inside the body 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 kinds of physical objects and hence have weight. This is exactly what Reis found. His five year olds said things like "I think that idea of 'animate' is because they are heavy." Clearly, this idea is incorrect for all children.

Principles for Learning about Number

Children have to learn the count words (one, two, three...) when counting objects. Someone 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-count principles, are: (1) the one-to-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 is unlike any other tag can represent the cardinal value of the set. Whereas these principles are constraints if they are not applied the behavior is not counting, the next two do not. Just as Sperling's principles have implications for the kinds of things children will not take as ent-
ical, so do the how-to-count principles. In particular, none of the assertions about the kinds of objects that can be counted together are stated explicitly. To illustrate the difference between the two types of counting, Gelman proposes (4) the abstraction principle--it matters not what kinds of objects and 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 B is the order irrelevance principle--the order in which the items themselves are counted is irrelevant.

There is evidence to suggest that preschoolers implicitly understand the five counting principles in addition and subtraction change the value of the set. It is not clear how many of these principles should be granted infants. That babies abstract numbers by the auditory and visual modality suggests the abstraction principle is part of their initial competence. And since the most straightforward account of their initial modality involves postulating an early form of one-to-one correspondence matching, at least some aspects of the one-to-one principle are also a component of their initial competence. Finally, very young children sometimes use the one-to-one principle in ways that are consistent with the standard count list. This indicates that they understand the stable-order principle to the language-learning task, a principle that focuses on the child's attention on items, which are clearly unrelated to 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 testifyingly on the question of whether the stable-order principle guided development or is inferred following the 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 two-year-old child from one of the many books that he has. One book contains many different objects on each page. On one page, there are objects such as cow, bus, cat, dog, apple, banana. On another day, he shows the child the same book and says "brown, green, red, pink, yellow!" On yet another day, he says "one, two, three, four, five." Picking up another book, he says "house, pig, man, sailboat, coast" then "white, red, orange, blue, red," 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 only 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 transcriptionist account, one might expect that children would either learn to use names for each object, learning to use only those names that are assigned further uniquely. Further, since every word was used with two different objects, children should have the hardest time learning to use these labels. But now that young children are predisposed to words that occur in orderly lists as terms to the counting principles are applicable labels. Also, the objects are grouped under sets of terms in a way that is consistent with the stable order principle. This assumption provides the thinking that words in a count list are names for any particular objects--evenually since we know they also have associations about the way labels for objects are supposed to be. Thus, the principles that young children are constrained by the mutual exclusivity principle--each object that have one and only one unique label. Principle 1 for naming and principles for counting, then, help young children make sense of what would otherwise be an unstructured verbal environment. The same may be the case with the child's use of learning color terms. The use of such terms at this stage may be the source of the child's mutual exclusivity principle and Spiro's rule that objects (as opposed to their parts or attributes) have naming priority.

Again, we must emphasize that principles may help get learning to a domain or 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 have trouble counting because they have to master the long list.

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 one-to-one 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 small-sized baby doll) in a row of objects and asked the child if she could count the objects so that the "baby" was "the two." 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 reverting to counting in the display. An example of a 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 item and tagged it "two," returned to the second and tagged it "three," skipped to the fourth and continued counting. An example of the second 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 said the names. Then, he could and did count from left to right. Such solutions reveal the child's facility with the one-to-one correspondence principle.

Of interest for the present discussion is that the rearrangement solution also reflects pruned knowledge that is not included in the five counting principles set forth earlier. These principles operate on guidance using numbers of tokens to represent the spatial positions (e.g., third, fourth or fourth in a row) of items in a set. The ordinal principle (6) does--an object in a spatially ordered array can be said to be in the nth position when the object procedure is order preserving. That, although it is true that tagging counting 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 accounts of early competence and add the ordinal principle? 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-to-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 counterpart 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 that as the conventional mode of counting. But notice what happens as a result. The child is presented with a case in point of a structural isomorph between the non-
n numerical 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 theme that young children often take control of their learning, are motivated to find structure, and learn rapidly if they can capitalize on structural mismatches 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 characteristic of young as vessels into which we pour goals of development 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 events. Consequently, we have a different view of the theories of development, notably Piaget's, 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, rules much in keeping with what is not identified to that of the scientist.

Study of sustained, self-motivated learning have typically been situated within simple problem domains. Yet, rapid learning is possible and it is easy to make progress. Indeed, for example, while working with children on solutions to a variety of stacking problems, children below 30 months of age began showing such a strategy as stacking a set of cups of gradually increasing size of a container to bristle force, when a large cup is placed on a smaller one, they usually twist, turn, or push the large cup. This nonfitting cup was also favored by younger children in a concentration on local constraints only, after trying to place two nonfitting cups together, the child tries to find a replacement for one cup, a minimal restructuring involving a relation between two cups at a time. A third characteristic is a pile of children below 30 months of age dismantle the entire set and start again whenever a cup does not fit.

One child (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, 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 top-down 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 the completed partial stack, pressing and turning again and again. When brute force fails, they dismantle the whole stack and start again. Similarly, being assembled 1, 2, 4, 5, and then encountering 3, the younger children reinsert 1 as a base.

Over the next period of a few days, however, two-year-olds learn progress from pecemeal activities and local fixes plays 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, and younger children are able to reassemble 1 as a base.

![Figure 2](https://via.placeholder.com/150)

**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 the lengths of blocks by trial and error. They spontaneously began experimenting to discover the rules that governed the world of these blocks, beginning with partial theories that accounted only for some of the blocks and persisting until they arrived at a more encompassing theory that accounted for all of them. See A. Karmiloff-Smith & M. 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 approach was to concentrate on the geometric center and attempt to balance all blocks at that point. This worked only for the length blocks, as weighted blocks were discarded as exceptions. Long and heavy blocks, 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 consistently 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 consistently weighted blocks by the rule of "heaviest weight first and then compensate." Inconsistently (or invariable) 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 reason for them. In so doing, they isolated a category of thinking that resulted in a single hypothesis for all the blocks. The children passed before balancing any block and roughly assessed the point of balance by balancing each block on their fingers. Their com

<insert text here>
principles and 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 easy 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

This paper was drafted during the summer of 1985, when the authors were fellows at the Center for the Study of Political Thought, at the Institute for Advanced Study in the Social Sciences, at the University of California, Berkeley.


2. Principles of knowledge are implicit if they are not explicit. The difference is crucial: if they are not explicit, they might not be used.

3. Spelke's perceptual principle resembles some of the principles proposed by Geissler (1967). They are similar in that both principles are principles of common sense. Thier differ, however, because they are not taken to be a principle of good form in order to identify objects. Spelke proposes that this tendency, as well as the use of gestalt principles like symmetry and parallelism, is learned. See his paper Cognition in Infant, MIT Press, 1983.


Additions to the Tyler Collection


R. Gelman & E. S. Spelke, "The child's knowledge about the difference between a name and a picture," in D. Rogoff, ed., The Development of Symbolic Thought (London: Erlbaum, in press.


