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Grounding Development in Cognitive Processes

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Developmentalists have made remarkable progress over the last several decades in detailing what children know at various points in development. Less progress has been made, however, in detailing the processes through which knowledge is realized in real-time tasks, or in detailing the processes of developmental change. We argue that the operating characteristics of perceiving and remembering provide a foundation for making progress on these issues in the next century. We include three examples applying these ideas to specific phenomena in early word learning. These examples illustrate how forming developmental hypotheses in terms of perceiving and remembering may bring new insights into specific phenomena as well as into how the ordinary operating characteristics of perceiving and remembering serve as bootstraps to more specialized and more abstract kinds of knowledge.

INTRODUCTION

> . . . our brain changes, and . . . like aurora borealis, its whole internal equilibrium shifts with every pulse of change. The precise nature of the shifting at a given moment is a product of many factors. . . . But just as one of them certainly is the influence of outward objects on the sense-organs during the moment, so is another certainly the very special susceptibility in which the organ has been left at that moment by all it has gone through in the past.
>
> . . . no two ideas are ever exactly the same, which is the proposition we started to prove. The proposition is more important theoretically than it at first sight appears. (William James, 1890/1950, pp. 234–235)

At the last turn of a century, William James argued eloquently for the idea of knowledge as fluid, historic, and dynamic. His view contrasts with the contemporary view of knowledge as fixed and constant, a view well illustrated in the following quote from Keil (1994),

> Shared mental structures are assumed to be constant across repeated categorizations of the same set of instances and different from other categorizations. When I think about the category of dogs, a specific mental representation is assumed to be responsible for that category and roughly the same representation for a later categorization of dogs by myself or by another. (p. 169)

The field of cognitive development has made remarkable strides under this view of knowledge as fixed representations. We have a deeper understanding of the seeds of competency in infancy, of the pervasive continuities in cognition across development, and of the distinctness of such domains of knowledge as number, space, people, objects, and language. The view of knowledge as fixed representations has led to less progress in two other areas: (1) in specifying how knowledge is effectively brought to bear in real time and in real tasks, and (2) in specifying the mechanisms of knowledge change, the mechanisms that turn the cognitions of 1-year-olds into those of 2-year-olds, and so on.

We believe that the field is now ready to solve these two problems. During the time that developmentalists so successfully characterized the knowledge infants and children possess, other experimental psychologists have made considerable progress in understanding the dynamics of perceiving and remembering. The result is a vision of knowledge closer to that of James. We believe that in the next century, coupling the dynamics of perceiving and remembering with the dynamics of development will lead us to a more complete theory of knowledge and its development.

In what follows, we briefly review the progress made in understanding perceiving and remembering. This progress leads us back to James—to the view of knowing as an event. This progress also takes us to a developmental theory in which the real-time activities of perceiving and remembering create cognitive development. We use examples from the domain of children's early word learning to illustrate the role of basic psychological processes in the developmental process.

PERCEIVING AND REMEMBERING

There are three foundational truths about perceiving and remembering: (1) perceiving and remembering depend broadly on the immediate input and its larger context; (2) perceiving and remembering are temporally extended processes with beginnings and ends that overlap and blend; (3) the processes of perceiving and remembering change as a direct consequence of individual acts of perceiving and remembering. These truths are textbook facts. *Any* theory of *any* psychological phenomenon must accord with them. But more importantly, these truths provide the basis for a *developmental* theory of cognition.

The immediate context. The first fact is contextual dependency. Figure 1 illustrates several standard examples of the role of context in perception. Panel A shows how the perceived size of an object depends on surrounding objects: an object looks smaller than it really is when surrounded by objects that are much larger, yet looks larger than it really is when surrounded by objects just slightly bigger than itself. Panels B and C show how the perceived similarity of two objects depends on other perceptually present objects. In Panel B, the perceived similarity of objects 1 and 2 is low but the perceived similarity of these same two objects in Panel C is high (for more relevant data on the context-dependency of perceived similarity see Goldstone, Medin, & Gentner, 1991). Finally, Panel D shows how the addition of a constant line, a small change in context, radically transforms shape and perceived similarity (Palmer, 1989). The importance of the context-dependent nature of perception should not be underestimated. It means that the psychological object, the object that must activate any stored knowledge representation, is not itself a fixed entity with one objectively correct description. Psychological objects present only subjective, not objective, truths.

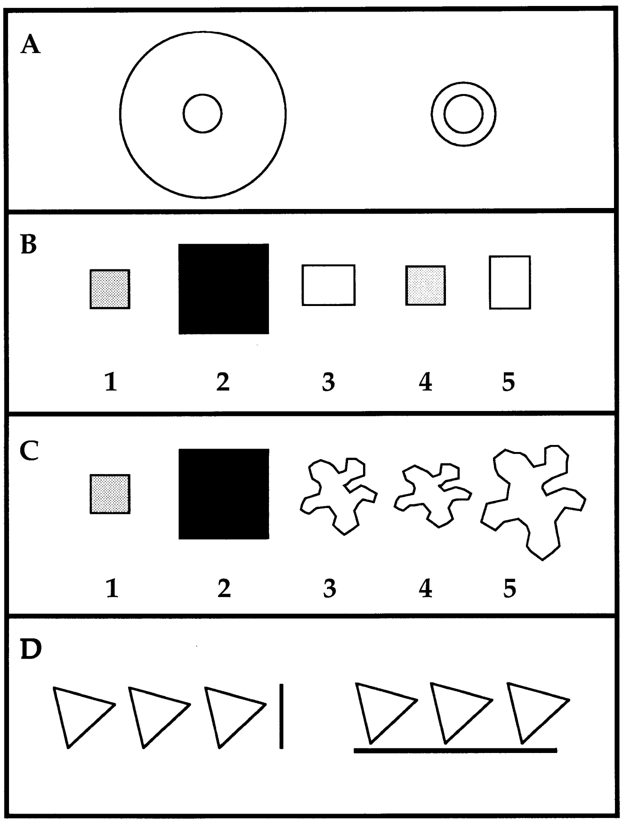

Figure 1 Illustrations of context effects in perception: (A) perceived size of inner circle depends on the size of the surrounding circle; (B) and (C) perceived similarity of objects 1 and 2 depends on the other objects in the comparison set; and (D) perceived shape and similarity of objects depends on the context created by the line.

Contextual malleability also characterizes memory phenomena. The perceptual effects in Figure 1 recall the classic von Restorff effect (1933). For example, the word "donkey" encountered in a list of animal names does not draw attention and is easily forgotten; the same word in the context of a list of foods, however, attracts attention and is not easily forgotten. Light and Carter-Sobel's (1970) hallmark demonstration of encoding specificity provides another good example of the contextual nature of remembering. They showed that the word "jam" encountered in the context of "traffic" does not lead to the same memory as the word "jam" encountered in the context of "strawberry." Further, the to-be-remembered word "jam" is better recognized by study participants in the context that matches the original learning (the word "traffic") than in one that is different. The importance of context goes far beyond this paradigm (see, for example, Tulving & Thomson, 1973).

Evidence from a variety of memory tasks indicates that what is remembered depends critically on a holistic match between the quite general context of the original event and the context of the moment. For example, in a developmental study, Butler and Rovee-Collier (1989) found that babies who had learned to kick to make a mobile bounce while they were in a crib with a particularly patterned crib sheet and bumper remembered days later what they had learned as long as the crib sheet and bumper were the same but not when they were different. Other evidence shows that the particular room, the particular voice of a speaker, and even the mood of the participant matter in terms of what is remembered and what is recalled. In sum, what we remember depends broadly on the context at the moment of learning and at the moment of retrieval.

These facts about the contextual dependency of perceiving and remembering have profound implications for cognition. The shared mental representations that are assumed to be constant across repeated moments of knowing must be engaged by processes of perception and memory, processes that are always contextually nuanced. To use Keil's (1994) example, each time he thinks about "dog" he can not think exactly the same thing. The context-laden nature of perceiving and remembering ensures that when "dog" is encountered, the thought will be uniquely and contextually appropriate. In the context of police, "dog" may lead to thoughts of ferocity, but in the context of rock music "dog" may lead to thoughts of Elvis. The contextual nature of perceiving and remembering mean that our momentary thoughts will be smartly fit to the idiosyncrasies of the here and now.

Continuity with the just previous past. The second fact about perceiving and remembering is that these processes are extended in time. Because the information bearing events that comprise perceiving and remembering take real time and endure, mental activity at any point in time is a mixed result of immediate input and just past activity. The journals and textbooks of cognitive psychology are filled with many examples that demonstrate how what we perceive depends on what we were perceiving in the seconds and minutes before: these include all those phenomena that fall under the rubrics of priming, adaptation, and assimilation. All these effects arise because of the transient changes in internal activity that are perceiving and remembering.

An experiment conducted by Treisman (1992) provides one good example of the dynamic blending of perceiving and remembering by demonstrating the integration of successive perceptions. Participants were presented with rapid displays of boxes containing lines. Treisman found that successive displays of horizontal and vertical lines at the same location were blended to yield perceptions of a plus sign. Other studies, including those with infants (e.g., Adler, 1997), demonstrate similar blending effects over longer time scales. And, importantly, these blending effects can result in changes in memories over time. When an immediate perceptual event activates a previous memory it can alter it as the immediate input and the activated memory become blended together (e.g., Loftus, 1977).

These assimilation, priming, and blending phenomena illustrate two important points. First, there is a pull for coherence from one thought to the next one, for the meaning of an event to depend on its place in a stream of events. Second, as James put it in the opening quote, we are unlikely to ever have the same idea twice. This is because what we think at any given moment depends both on the state our cognitive system has been left in by what we have just been perceiving and remembering, and on the current input and its larger context.

A history of individual acts of knowing. The third fact about perceiving and remembering is that these processes themselves change. We know long lasting changes must happen or we would have no memories of the individual events of our own lives and no connectedness with our own past. One empirical example of how a single processing event can alter subsequent knowing is Jacoby, Kelley, Brown, and Jasechko's (1989) ability to make people famous overnight. They had subjects read a list of names that included only nonfamous people, names such as *Samuel Weisdorf.* Twenty-four hours later they gave subjects a list of famous and nonfamous names and asked subjects to pick out the famous people. Subjects picked out *Samuel Weisdorf* along with *Minnie Pearl* and *Christopher Wren.* Having read the name *once* was sufficient to create a lasting degree of familiarity—one sufficient for a categorization of the name as "famous."

A second example is Perris, Meyers, and Clifton's (1990) dramatic demonstration of toddlers' memory of a single experimental session that occurred in their infancy. The original experimental event was designed to test infants' use of visual cues to control reaching. To do this Perris and Clifton (Clifton, Perris, & Bullinger, 1989; Perris & Clifton, 1988) taught 6-month-old children to reach in the dark for different sized objects. The different sizes were signaled by different sounds (e.g., bells for big objects, squeaks for little ones). One to two years after the original experiment, Perris et al. (1990) brought these children back to the laboratory. At this test session, the lights were simply turned off, the sounds played and the children's behavior observed. Perris et al. found that the children who had been in the experiment as babies reached in the dark for the sounding objects; control children who had not participated in the infant study did not. Thus, the one-time experience at 6 months of age permanently changed these children, altering the likelihood of behaviors one and two years later.

There are other demonstrations in the literature of long-lasting facilitatory effects—of the benefits of a single prior processing experience (with units as small as single words) that has effects days, weeks, and even years later. Such results indicate that each act of perceiving and remembering changes us. The accrued effects of such long-term changes bring stability to cognition—the same stability that is the focus of Keil's (1994) characterization of knowledge. Stabilities will emerge, if there are regularities, as successive moments of knowing are laid on preceding ones. Over time, any regularities that hold across individual experiences will coalesce; weak tendencies to think in certain ways will become strong tendencies. Such long-term changes in perceiving and remembering constitute knowledge that can be highly stable. But notice that this knowledge is not in any way distinct from the real-time processes that create, activate, and blend past memories with the here and now. It is the emergent product of these same processes.

KNOWLEDGE AND DEVELOPMENT

Viewed from the perspective of perceiving and remembering, knowing is creative, the melded product of multiple processes operating over multiple time scales—the milliseconds of sensation and perception, the seconds and minutes of ongoing tasks, and the years of learning and remembering. As such, what we know in a moment, at some real point in time, cannot be attributed to knowledge independent of real-time processes. A study by Goldstone (1995) clarifies this point. He asked adults to judge the hue of objects by adjusting the color of one object (the target) until it matched precisely another (the standard). The individual objects were letters and numbers presented to participants in a random order. Unbeknownst to the participants, Goldstone had arranged for the colors and objects to be correlated across trials such that the letters tended to be redder than the numbers. This fact strongly influenced participants' judgments. They judged presented letters to be redder than numbers of the exact same hue. Apparently, participants' lifetime history of experience with letters and numbers caused same category members to influence each other in the here and now. Long-term category knowledge interacted with both the transient effects of seeing redder letters than numbers and the sensory information presented by the single to-be-judged object. In this way, processes operating over different time scales combined in a single moment of knowing to make an individual letter *look* a particular degree of red.

Goldstone's (1995) results suggest how ideas exist as the products of process. Individual mental events with real time durations are the product of a lifetime of perceiving and remembering combined with the current state of the system and the immediate input. In this way, knowledge is the on-line product of complex processes of perceiving and remembering. And as such, knowledge is both dynamically stable, reflecting regularities emergent over a lifetime, and also adaptively inventive, as those stabilities are mixed with the idiosyncrasies of the present. These foundational processes of knowing may, in the twenty-first century, also be understood as the foundational processes of cognitive development.

Figure 2 provides a schematic depiction of how development might emerge from the operating characteristics of perceiving and remembering. The activity of the many heterogeneous and interacting subsystems that comprise a single moment of knowing is represented by $*_t$. The causes of the activity at a single moment of knowing are the immediate input, the just previous activity of the system, and the nature of the cognitive system itself. The immediate input to the system at a particular moment in time is represented by I_t. The multiple processes of perceiving and remembering are indicated by arrows between the input and the individual moment of knowing, and between one moment of knowing and the next. Importantly, since the activity at $*_t$ is in part determined by the activity at $*_{t-1}$, it is also partly determined by the activity at $*_{t-2}$, $*_{t-3} \ldots *_{t-n}$. Each moment of knowing thus brings with it the history of its own past activity. Further, since each act of knowing permanently changes processes of perceiving and remembering, the accrued activity changes the cognitive system itself. It will not be the same at t_n as it was at t_{n-1}. The three truths about perceiving and remembering thus unify real time and developmental time, the same processes that bring knowledge to bear in a moment change as they do so, creating the developmental trajectory that is cognitive development. Developmentalists should recognize the larger ideas about developmental process in this picture; they are similar to Piaget's early theory in which cognitive change emerges progressively out of the child's interactions with the world (Piaget, 1952). In Figure 2, as for Piaget, each interaction is the product of past interactions and a causal agent of change potentiating future interactions.

What do we need to do to realize this vision, to ground developmental process in psychological process? Certainly we need to study basic processes of perceiving and remembering developmentally. This is an endeavor with a long and notable tradition (Bauer, 1997; Flavell, Friedrichs, & Hoyt, 1970; Gibson, 1988), and one we predict will be increasingly recognized as central to the study of cognitive development. But, if the vision of Figure 2 is correct, we also need to ground domain-specific knowledge in general processes of perceiving and remembering. We predict that this unifying approach to process, knowledge, and development will also take center stage in the next decades. We illustrate this approach with examples from early word learning.

EARLY WORD LEARNING

Very young children appear to possess domain-specific knowledge about words, objects, and how people use words to refer to objects. For example, considerable evidence suggests that one reason children are so facile in learning object names is that they know something about speakers' intentions and the social pragmatics of discourse: specifically, they know that

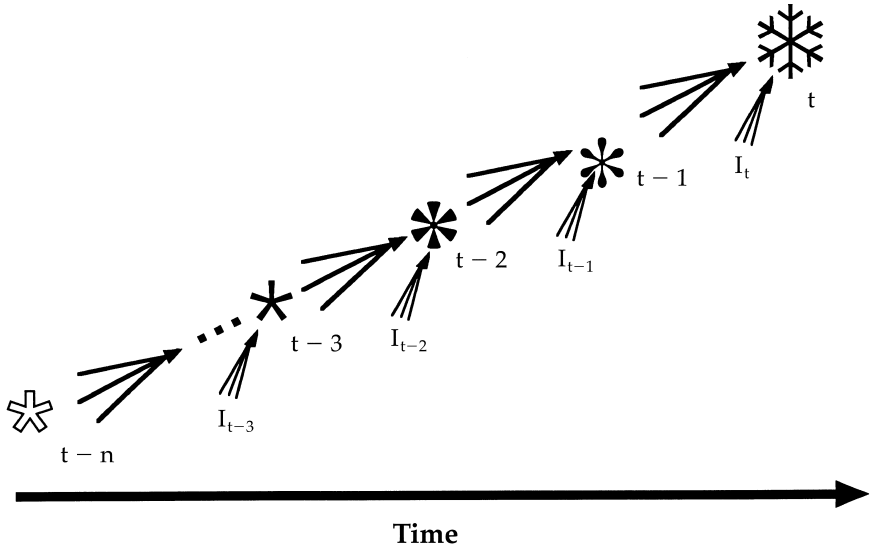

Figure 2 **Schematic depiction of development as the combined product of the current input, the just previous activity, and a history of individual moments of knowing.**

people name an object when it is first introduced (e.g., Akhtar, Carpenter, & Tomasello, 1996), that people label objects that are the focus of attention (e.g., Baldwin, 1991), and that a new noun refers to an object that has not already been named (Markman, 1989; Merriman & Bowman, 1989). Other evidence suggests that a second reason why children are so facile in learning object names is that they know something about how nouns map to categories: specifically, they know that common nouns refer to categories of similar objects, and not to individuals (Katz, Baker, & Macnamara, 1974); that nouns refer to taxonomically and not thematically related objects (e.g., Waxman, 1994); and that count nouns refer to rigid objects that are similar in shape (Landau, Smith, & Jones, 1988).

All these facts point to knowledge. But where does this knowledge come from? And how is this knowledge brought to bear and realized in real time when a child encounters a real speaker and a novel object? Increasing evidence suggests that the answers may be found in the operating characteristics of perceiving and remembering (Merriman & Stevenson, 1997; Roberts & Jacob, 1991; Saffran, Aslin, & Newport, 1996; Smith, Jones, & Landau, 1996; Stager & Werker, 1997). We briefly consider three lines of evidence from our own work.

The first example concerns children's knowledge about social cues to the speaker's intended meaning. In one experiment Akhtar et al. (1996) showed that if a speaker offered a novel object name ambiguously (so it could be taken as referring to any one of four objects), 2-year-olds systematically interpreted the name as referring to the object that was novel in the discourse context—not to themselves, but to the speaker. This suggests that children take the speaker's perspective into account when determining word meaning.

This impressive accomplishment may fall directly out of the contextual nature of perceiving and remembering. It is a kind of von Restorff effect, attention attracted to the object that is *novel in the context.* In Akhtar et al.'s (1996) case, the object attracting the child's attention at the moment of naming was novel in the context of the speaker and the discourse setting. We (Samuelson & Smith, 1998) replicated Akhtar et al.'s study, but made the object novel in context by manipulating the nonsocial context (location in the room). And we, too, found that children linked the novel name to the object that was *novel in the context.*

By one interpretation, these results could be seen as undermining Akhtar et al.'s conclusion that 2-year-olds use social cues and, more specifically, knowledge about the speaker's perspective, to determine the intended referent. After all, our results showed that a discourse-relevant shift was not necessary for the effect to obtain. Another way of thinking about the original Akhtar et al. result, however, is that the ordinary workings of memory and attention took the child to the right *social* interpretation. It makes sense that perceiving and remembering in and of themselves will often take the child to the intended referent of the speaker. The child and the adult have in common general processes of perceiving and remembering that work in the same way. Thus, the listener and the speaker can be thought of as coupled cognitive systems; what pulls one person's attention is likely to pull the other's attention. This is profoundly important developmentally; it is the potential source of knowledge that is specifically about the pragmatics of communication. The dynamic coupling of the child's attention to the adult's attention *and* to the adult's more mature intentions and meanings will lead over time to change. Bootstrapped by the adult partner, the child's perceiving and remembering will become laden with social–communicative meaning.

A second example of how domain-specific knowledge about words may be grounded in general psychological processes concerns categories. Words appear special in signaling and creating categories; as Waxman (1994) notes, words are potent forces in children's category formation and seem to "invite" children to form categories. The power of naming is easily seen in studies contrasting naming and non-naming classification tasks (e.g., Gelman & Coley, 1990; Landau et al., 1988; Soja, Carey, & Spelke, 1991). For example, when objects are named young children group them taxonomically, but when they are not named they group them thematically (see, e.g., Waxman, 1994). The power of words in creating categories is guaranteed by two general facts about perceiving and remembering: (1) that memory is by nature contextually cued, and (2) that current input blends into the memories activated by that input.

Consider two objects labeled with the same name at two different times, for example A and B in Figure 3, and the memory, C, that might result from the integration of these experiences. Because words operate as stable context cues, when a word is paired with an

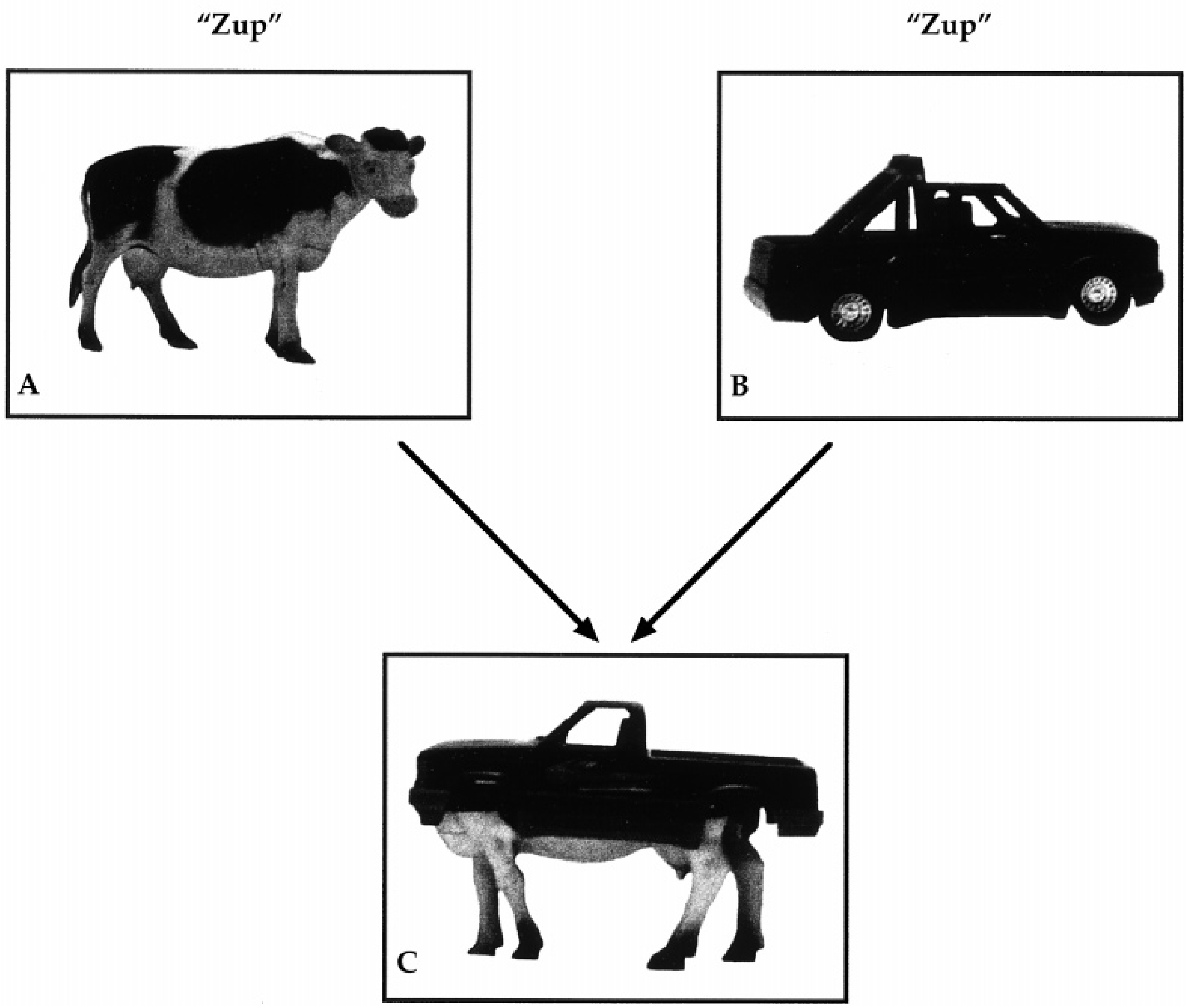

Figure 3 Illustration of (1) how words may create cohesive categories by acting as context and retrieval cues that create memory blends, and (2) the stimuli used in Samuelson & Smith (1999).

object, the word will activate prior associates and blend them with the current input. In this way, words will naturally bundle the individually experienced instances of a category into a cohesive unit.

Results from a current study (Samuelson & Smith, 1999) show just how potent this contextually cued blending is. Following the logic of Figure 3, we showed 14-month-olds exemplar objects from two different superordinate categories, a cow and a car. We showed children the cow and said "This is a zup." Later, we showed them the car and said "This is a zup." If the associated name causes the memory of the cow (the first object named) to be activated when the car is labeled with the same name, and if the simultaneous perceiving and remembering creates a memory blend of the two, then "zup" should be associated with a memory that is both cow-like and car-like. To test this, we asked whether children generalize "a zup" to objects that blend cow and car properties (like that shown in Figure 3, and like those used earlier by Rakison & Butterworth, 1998). We found that 14-month-olds generalized the name to the blend 67% of the time in a two-choice task. Children in a control condition who heard the two different exemplars named with different names (i.e., "This is a dax," in reference to the car and "This is a zup" in reference to the cow) chose the blended object only 43% of the time. Importantly, it is not that children who heard the cow and car both called "zup" thought that anything could be called a "zup"; that children from both conditions chose out-of-category test objects (e.g., a carrot or cup) equally often and at levels that did not differ from chance. The results indicate that naming quite different objects with the same name causes them to be conjoined in memory. This is a powerful force on category formation, one that should rapidly build cohesive and coherent categories given objects of the same kind with overlapping similarities. In sum, from the perspective of the operating characteristics of perceiving and remembering, words are powerful in creating categories and in enabling children to activate the richly correlated associations that constitute kinds because words are stable context cues that invite memory blends.

The third and final example of how perceiving and remembering make domain-specific knowledge concerns the accrued effects of learning many names for things in many categories. Although young children become smart and fast word learners, they are not so skillful at the beginning of language acquisition. Instead, lexical acquisitions are initially slow and error-full; children make such mistakes as calling all vehicles from bikes to planes "car," calling oranges, fingernails, and plates "moon," or calling swans and robins "duck" (Clark, 1973; Macnamara, 1982; Mervis, Mervis, Johnson, & Bertand, 1992). Noun learning becomes fast and seemingly error-free only after children have already learned some nouns. This kind of developmental course, one that accelerates and becomes self-directing, is just what is expected by the ideas portrayed in Figure 2. Self-accelerating and self-directing developmental trajectories are the expected consequence of processes that are context dependent, extended in time, and that change themselves through their own activity.

Evidence for the self-accelerating and self-directing nature of early object name learning is provided by recent studies of the origin of the shape bias (Samuelson & Smith, 1999; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 1999). Older word learners, 2- to 3-year-olds, systematically interpret novel names for solid rigid artifacts as referring to things of the same shape (e.g., Landau et al., 1988). In a 5-month longitudinal study of children from 15 to 20 months, Smith et al. (Smith et al., 1999) tracked both nominal vocabulary growth and, in a laboratory task, children's generalizations of novel nouns to new instances. At the beginning of the study, children acquired new nouns (outside the laboratory) slowly, and generalized novel nouns to new instances (in the laboratory) unsystematically. The nouns these children were slowly and laboriously learning outside the laboratory, however, were predominantly of one kind. Most of them were count nouns (about 67%) and virtually all of these early count nouns (over 90%) referred to categories that are (by adult judgment) well organized by shape. After children had learned about 35 of these shape-based categories, noun learning outside the laboratory accelerated. And, at the same point, children began to systematically extend novel names to new instances by shape in the laboratory. It seems that as children were slowly learning particular nouns they were also learning how to learn new nouns, and in so doing they were becoming faster noun learners.

This suggests (1) that the shape bias is not just a product of early noun learning, but also a mechanism that, once formed, speeds the learning of object names, and (2) that intensively teaching names for shape-based categories in the laboratory ought to accelerate noun learning outside the laboratory. Accordingly, Smith et al. (1999) recruited eight subjects who were 17-months-of-age and had (on average) 14 count nouns in their productive vocabularies. For 7 weeks the children were taught names for four different novel categories all well organized by shape. At the end of training the children had acquired a shape bias that generalized to novel objects and novel names. Eight control children who did not participate in the training did not show a shape bias at the end of the experiment. Further, the count noun vocabulary of the children in the training condition increased 166% from the beginning to end of the experiment; that of the control children increased only 73%. Thus, the children who were taught names for categories well organized by shape also learned more names for real categories outside the laboratory. Learning shape-based lexical categories created a shape bias which in turn promoted the rapid learning of object names.

This example provides a compelling illustration of how the accrued effects of individual moments of perceiving and remembering will make knowledge. During the training, children were taught simple associations between specific names and specific objects. But, we maintain, through the ordinary workings of perceiving and remembering something much more emerged—attention to shape in the context of naming an object. This attentional bias, made through experience, then becomes a strong force on subsequent development, promoting the learning of names for other similarly structured categories. In this way, the dynamic, historical processes of perceiving and remembering create increasingly constrained destinies.

CONCLUSIONS

Cognition *is* perceiving and remembering. These are the processes through which we make contact with the world and with all that we know. As such they are essential to understanding knowledge and knowing. They may also be the driving cause behind cognitive development. Cognitive development may not exist separately from these processes, but proceed only through them. All that we have achieved in the last century—in the study of cognitive processes and in the study of knowledge and cognitive development—prepares us to focus in the next century on grounding developmental process in psychological process.

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