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Slowing Down Fast Mapping:

Redefining the Dynamics of Word Learning

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Abstract

In this article, we review literature on word learning and propose a theoretical account of how lexical knowledge and word use emerge and develop over time. We contend that the developing lexical system is built on processes that support children's in-the-moment word usage interacting with processes that create long-term learning. We argue for a new characterization of word learning in which simple mechanisms like association and competition, and the interaction between the two, guide children's selection of referents and word use in the moment. This in turn strengthens and refines the network of relationships in the lexicon, improving referent selection and use in future encounters with words. By integrating in-the-moment word use with long-term learning through simple domain-general mechanisms, this account highlights the dynamic nature of word learning and creates a broader framework for understanding language and cognitive development more generally.

Word learning in children has been described as a sequence of events: an initial *fast-mapping* process in which children form preliminary links between words and referents, followed by *slow mapping* that builds on these memories (1). While a few studies have examined slow mapping (e.g. 2, 3), most research on early word learning has emphasized fast mapping. Researchers have framed this stage in terms of ambiguity; given the many kinds of words to learn, the learner's lack of knowledge, and the minimal information in the moment, the task of mapping a novel word to its meaning seems underconstrained. This has resulted in claims that domain-specific processes internal to the child—interpretive biases or social-pragmatic skills—overcome ambiguity and serve as the fundamental route to learning words.

Much work on fast and slow mapping has assumed two distinct learning periods operating in a stage-like manner. In this article, we argue that the distinction between fast and slow mapping is unwarranted—separate stages are not needed, and the data do not support such a distinction. It is more fruitful to distinguish the processes that support word learning in terms of their time course, and the behavioral and functional goals they serve. This point of view reduces the need for specialized mechanisms, leaving domain-general mechanisms to solve the problem of referential ambiguity and account for early word-learning behavior.

Findings from recent studies are consistent with the idea that children's lexical development involves processes operating over two distinct but interactive time scales. In *situation time*, children determine a referent or produce a word to support communication in the moment. Over the longer *developmental time* of repeated encounters or uses of a word, a network of mappings between words and concepts is created and refined. While this distinction is similar superficially to fast and slow mapping, communicating in the moment and refining words over experience are functionally distinct behaviors that accomplish distinct goals.

Consequently, these processes do not operate sequentially, though they each may influence the child simultaneously. Thus, in situation time, a confluence of mechanisms helps the child behave and communicate. The outcome of such processes may be a form of inferring, solving problems, or satisfying constraints but, as we will argue, these processes are not isomorphic with learning and any learning they produce is minor. In contrast, in developmental time, a slow and gradual learning process augments and refines the network of accumulating mappings built from the outcome of situation time processes and slower associative/statistical mechanisms, forming a durable vocabulary.

In the following sections of this article, we review recent literature on word learning and describe how lexical knowledge and word use emerge over time. We highlight two unique consequences of our reframing: that the goal of biases, constraints, and other fast-mapping processes proposed to deal with referential ambiguity is not learning, and that learning may be based on a range of simple mechanisms, some of which had previously been ruled out as too gradual. In addition, we show how this approach provides new insight into the relation between the processes that support word learning and word use, and also connects developments in word learning to language acquisition and cognition through its reliance on domain-general mechanisms.

Motivation

The case for independent time scales is best illustrated by two complementary lines of research. In a seminal study by Horst and Samuelson (4), 24-month-old children were given a standard fast-mapping experience—a novel name in the context of one novel and two known objects. Children selected the novel object accurately. Nevertheless, five minutes later they were unable to remember the novel name. Another study (5) replicated this effect with 24-month-olds and also found that by 30 months, children could retain the novel name over a short delay. While we would not claim that children learn nothing from fast-mapping experiences, these studies illustrate that whatever learning does occur is minor and does not support even short-term recall.

In the second line of research, learners were exposed to trials presenting several novel names and objects with no disambiguating information. Children and adults used co-occurrence of names and objects to learn word-referent mappings (6), suggesting that word-object mappings can be mastered without solving the problem of referential ambiguity. While we would not argue that learners do not engage biases or inferential processes in such circumstances (c.f., 7), this work demonstrates that referential ambiguity need not be resolved for some learning to occur.

The implications of this research combine in interesting ways. Even if children have only partial lexical knowledge, they may still be able to behave appropriately in situation time to interpret a request. Or, even if the scene is ambiguous, children may still be able to acquire something useful from a naming situation. Thus, the critical issues are what mechanisms allow children to engage in processes at both the situation and developmental time scales, and how do those processes interact?

Behaving in Situation Time

Even if the processes operating in situation time are not isomorphic to learning, to communicate, children must figure out what a speaker is referring to in the moment. Clearly weighing possible interpretations given the information in a situation is one important part of this active inference or decision-making process. It is tempting to see these as largely rational, inferential, and domain specific—geared toward solving the problem of referential ambiguity.

Indeed, many classic word-learning biases (e.g., mutual exclusivity, whole object, novel name-nameless category) could be framed this way, although they may also derive from simpler mechanisms (8, 9). However, recent studies suggest that a confluence of simpler and often nonlinguistic systems contribute to these emergent decisions and support in-the-moment communication.

Fundamentally, identifying the referent of a word (either novel or familiar) is a matter of orienting attention. Children's attentional systems are driven by both external cues like salience and internal cues like novelty biases. Both change over time as children learn about the stimuli in the task (10). In word learning, children as young as 10 months are sensitive to the relative novelty of word forms and referents (11). While this will not necessarily get children to the level of adult semantics, a bias to attend to novel objects when words are novel could act like high-level reasoning biases by which children infer that a novel name maps to the novel object. Thus, novelty can shape behavior, even when it is seemingly uninformative, such as in a study in which 24-month-olds used *only* relative novelty to select a word's referent (12). Furthermore, novelty evolves over time: The same object receives less and less attention over repetitions (13), and novel objects attract less attention as word learning progresses (14). Thus, novelty and salience play a critical role in referent selection.

The ecology of word learning provides even more support for children's in-the-moment referential understanding via the properties of children's bodies and their interactions with caregivers. Studies involving head-mounted cameras and eye trackers illustrate that, because of their short arms and small stature, young children can view few items during object naming (15), significantly reducing referential ambiguity. Furthermore, as the people children speak to most often (i.e., their caregivers) are more linguistically mature, aspects of social context aid referent selection. Adults limit the possibilities by holding and naming a single object and labeling things children are attending to. Children themselves limit referential ambiguity by following discourse cues or switching attention to what the adult is holding when speaking (16). Thus, the external dynamics of the naming situation—shaped by both intelligent language partners and unintelligent properties of the body—help children understand the correct referent in the moment.

Learning in Developmental Time

We have shown that many domain-general and nonlexical processes work together to support infants' selection of a referent in situation time. These processes are not necessarily geared to the task of adding an entry to the lexicon. Rather, they are about behaving in the moment—selecting something when given a command (e.g., "Get your cup"). But if that is the case, how do children go from smart, in-the-moment behavior to a rich, robust lexicon? The answer lies in the slow accumulation of small bits of learning during and after each situation-time behavior. This is most clearly suggested by cross-situational learning studies in which children acquired robust links between novel words and referents, even when they did not have to identify the correct referent on any given trial (6). Similarly, although retention following the first presentation of a novel word-referent pair is minimal (4), it rises systematically with repetition (11) and vocabulary development (5).

However, even in these cases, what children learn is not strictly lexical. Children encode more than the referent; they also encode co-occurrence of nontarget items (17), context features (18), and spatial locations of referents (19). For example, if a child sees a cup and a shoe on the table when hearing *cup*, he or she builds links not only between *cup* and the object cup, but also between the word and the shoe and table. Over time, the object cup is more likely to be present when *cup* is heard, and spurious links can be pruned leaving *cup* associated strongly with the object cup, partially associated with the semifrequent table, but not linked with shoe (6, 8). Over longer time scales as cups are labeled in more diverse settings, the word will become less bound by context and more closely tied to the right associates (20). Nevertheless, the additional associations influence subsequent behaviors and may contribute to word learning. For example, associations between objects and spatial locations facilitate name-object mappings (21), and just one minute of exposure to objects prior to referent selection boosts retention (22). Such narrowing from context-bound to abstract representations and learning to learn are hallmarks of many classic notions in learning theory (23, 24), suggesting a continuity with fundamental principles of learning.

A Developmental and Dynamic Approach to Word Learning

Thus far, this review suggests that situation-time referent selection and developmental-time learning are multifaceted and served by domain-general processes. Dynamic processes like novelty and attention as well as ecological factors like the properties of the body and communicative context operate in situation time to enable children to use words intelligently. These are supported by gradual learning that links referents to word forms and refines these links via statistical learning and the slow accumulation of small bits of knowledge. Thus, we do not need to posit fast mapping undergirded by specialized learning mechanisms to account for children's smart, in-the-moment behaviors; instead situation-time dynamics buttress partial knowledge to yield behavior that, though occasionally fragile, looks accurate. Similarly, interactions across time scales mean that situation-time behavior can be shaped by a child's history of associating words with referents, behaviors, and contexts, without recourse to information-laden biases and constraints.

Indeed, the mechanisms subserving this system can be simple. Following McMurray, Horst, and Samuelson (8), we propose that real-time competition underlies situation-time processing. Competition has been posited in categorization, word recognition, visual comparison, visual search, and speech production (25-27); here, it means that upon hearing a word, potential meanings are activated and compete until one wins. This mechanism balances many inputs and constraints to support in-the-moment behavior even if the child does not yet know the full meaning of a word. Similarly, unsupervised associative mechanisms can be the basis for learning. These mechanisms build stronger links between words and objects whenever they exist together, and they can harness both ostensive naming and cross-situational statistics to learn word-object mappings.

However, we are not invoking the simple input→output version of associative learning that is often the strawman of language acquisition debates. Rather, we refer to the mechanisms by which representations—perceptual *and* conceptual—gradually form links over experience. Such a framing can be powerful considering the nonobvious consequences of change in a *network* of associations, and when we consider what real-time processes can do with these associations. Moreover, associative learning rules are sensitive to how strongly items are considered—more active items form stronger connections. Since this strength is shaped by real-time processes (e.g., novelty, attention, social dynamics, and competition), this offers a clear mechanism by which referent selection in situation time can alter the associative network over development. Thus, the process of learning—strengthening a connection between a word and object—is the same whether it is the first time a child has encountered a word or the fiftieth.

However, the functional consequences of building this connection differ based on the real-time processes that drive attention to an object, since real-time processes are shaped by what the child has learned previously.

Furthermore, while associative learning has been criticized as slow, slower learning may be more likely to result in the right mappings. This is essential. With the literature's emphasis on learning nouns, it is easy to forget that word meanings are not static—words must be used flexibly (28, 29). The meaning of adjectives like *large* and *small* depends on the noun to which they are applied (small elephants, large ants); a word like *cool* means different things depending on context; and even words like *chicken* can refer to a bird, food, or a schoolyard taunt. It is counterproductive to overcommit to one meaning after a single exposure. Rather, a child should make the best decision in situation time, but then only learn a small amount, holding options open to determine the range of meanings across situations. While this argues for slow learning, the coupling with dynamic situation-time processes enables children to act in situation time even when there is much learning yet to do.

In addition, associative learning enables a process by which children can both *build* correct word-referent links and *prune* links between words and incorrect referents (30). Computational modeling shows that such pruning can lead to sophisticated developmental changes (31). As unsupported links are pruned, referents are selected more rapidly (8), just as children choose references more rapidly as they get older (32). Likewise, learning apparently speeds up as irrelevant connections are reduced and remaining links are supported by co-occurrence across contexts (33), or as the associative network becomes more organized, allowing stronger activation of items in situation-time referent selection.

Moreover, accumulated learning in the system changes its future processing and creates interactions that span timescales. Thus, the likelihood of retention from a single episode grows with the accumulating vocabulary (5, 34). This can account for the many classic studies that equated fast mapping with one-shot learning (see 4 for discussion). In those studies, single words were spoken in the presence of single objects, reducing the number of spurious connections strengthened, or participants were older children whose networks had already undergone pruning (4). However, in our view, such phenomena in older children are the developmental product of prior episodes of referent selection and learning, not the cause (8). That is, inferential biases like mutual exclusivity or shape biases are a consequence of appropriately structured or pruned associative networks, which has consequences that shape real-time referent selection and generalization. For example, the same stimulus can elicit incorrect selection in an 18-month-old, but is a seemingly rational choice for a 24-month-old (35, 36). Thus, although the learning process—strengthening and weakening associations between words and referents—is the same every time a word is processed, embedding this learning in a dynamic lexical system can result in striking differences over development.

Broadening the Role of Simple Mechanisms

We have argued that the developing lexical system is built on the interaction of children's in-the-moment word usage with long-term learning. This account puts simple, content-free processes like associative learning and competition, rather than language-specific knowledge, at the heart of lexical development. This generality links word learning to broader work in language and cognitive development, showing the influence of general perceptual, attentional, and memory systems in early word learning (37), speech perception (38) and category abstraction (39). In all cases, learning occurs both in situation time and developmental time. Thus, our account can unify understanding of word learning from parsing of the speech stream, to establishment of rudimentary mappings, to word use and generalization.

Our account also forces a rethinking of many phenomena. For example, Byers-Heinlein and Werker (40) suggest bilingual children do not use mutual exclusivity during a referent selection task. One could explain this as monolinguals acquiring a reasoning principle (most objects have one name) that bilingual children do not acquire (since for them, most objects have two names). However, the computational model of McMurray and colleagues (8) showed how such principled behavior can derive from purely associative learning coupled with competition without any capacity for such general principles. Similarly, this account reframes cross-situational word learning not in terms of inference mechanisms (e.g., propose and verify; 7) but as the gradual acquisition of associations, which can enable explicit decisions.

Our view identifies simple, separable mechanisms like association and competition, and their emergent interactions as the basis for building and using a lexicon. The dynamic interaction of referent selection and gradual strengthening or pruning of prior mappings in a lexical network enables children to make smart, in-the-moment inferences about words that cascade to improve retention. This in turn increases vocabulary, improving referent selection and learning. And because these ideas can be implemented in a simple, dynamic, associative network, they bridge from babies' first exposure to a word and referent to their seemingly quick acquisition and use of a robust and dynamic lexicon.

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