

Taking stock as theories take shape

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Our goal in this paper is to consider early word-learning, taking the *shape bias* as a case in point for discussing theories of development. We engage this discussion by touching on pertinent theoretical issues raised in the papers under consideration and the empirical evidence supporting them. We first review our research in early language and conceptual development, and then locate our (relatively recent) interest in the shape bias within this broader context.

A broad theoretical perspective

Our theoretical perspective embraces four clear conclusions from the developmental literature. First, human infants have an impressive store of conceptual knowledge (e.g. Baillargeon, 2002; R. Gelman, 1990; Keil, 1994; Mandler, 1988; Spelke, 1994). Second, they learn words rapidly (see Bloom, 2000; Waxman & Lidz, 2006). Third, their advances in word-learning and conceptual development are intertwined from the start (see Booth, Waxman, & Huang, 2005; Waxman & Lidz, 2006 for reviews). And fourth, these advances are fueled, at least in part, by keen perceptual and associative capacities which permit infants to discover the linguistic units (including syllables, words and phrases) and the relevant conceptual units (including individual objects, object categories, object properties, actions and relations involving objects), and to calibrate the relations between them (e.g., Aslin, Saffran, & Newport, 1999; Gomez & Maye, 2005; Murphy, 2004; Quinn & Johnson, 2000; Saffran, 2003; Younger, 1990).

In our view, then, a comprehensive approach to word-learning will consider infants' linguistic, conceptual, and perceptual capacities as well as the relations among these as they unfold. It will do so by identifying what capacities or expectations, if any, infants bring to the task of word-learning each step along the way, and how these are shaped by experience. This approach will require attention to both the structure inherent in the input and the structure inherent in the mind of the learner. Recent research in word-learning has made great strides toward integrating these potential engines of acquisition

(Bloom, 2000; Bornstein et al., 2004; Cimpian & Markman, 2005; Clark, 2004; S. A. Gelman & Coley, 1991; S. A. Gelman & Diesendruck, 1999; Golinkoff et al., 2000; Hirsh-Pasek, Golinkoff, & Hollich, 2000; Hoff & Naigles, 2002; Hollich et al., 2000; Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Markman, Wasow, & Hansen, 2003; Samuelson, 2002; Tomasello & Akhtar, 2003). The current mandate is to carry this integrative movement forward by developing theories that specify as precisely as possible the balance between the input and the learner, and to trace their interplay as development unfolds (R. Gelman & Williams, 1998).

Points of divergence between our view and the associative learning account

Our approach to addressing this mandate differs from that of the associative learning account (ALA) in (at least) three principled, inter-related ways.

A broader developmental window. First, we focus on a broader developmental window, opening long before the shape bias begins to exert its influence on word learning (Samuelson, 2002; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002). We have demonstrated that infants begin the task of word learning with a basic expectation linking words in general (e.g., nouns, adjectives, verbs) to a wide range of candidate meanings, including categories (e.g., dog), properties (e.g., fluffy), and actions (e.g., barking) (Waxman, 1998, 2002a; Waxman & Booth, 2003; Waxman & Lidz, 2006). The stage is then set for the evolution of more precise expectations linking particular grammatical forms to their associated types of meaning. For example, by 14 months, infants acquiring English tease the nouns apart from other grammatical forms (e.g., adjectives, verbs) and map them specifically to object categories (rather than to surface properties like color or texture) (Booth & Waxman, 2003b; Waxman, 1999; Waxman & Booth, 2003; Waxman & Braun, 2005; Waxman & Markow, 1995; Xu, 1999). By roughly 21 months, infants have carved out a more precise expectation for adjectives, linking them to properties (and not categories) of objects (Booth & Waxman, 2003b; Mintz, 2005; Mintz & Gleitman, 2002; Waxman & Markow, 1998). By 24 months, they have begun to map verbs specifically to event categories (Echols & Marti, 2004; Waxman, Lidz, Braun, & Lavin, under review).

Thus, over the first two years of life, we see a cascading set of expectations: infants detect increasingly precise relations between kinds of words and meaning in their

native language. We have discussed how associative processes figure importantly in these early developments by helping infants to detect regularities in their native language (Booth & Waxman, 2003b; Waxman, 2002b; Waxman & Lidz, 2006). However, the associative learning account has not yet addressed these early advances and has focused instead on a developmental window that opens later, sometime in the second year.

The contribution of conceptual information. A second difference concerns the contribution of conceptual information to early word learning. One goal of the ALA appears to be to explain early word-learning without appealing to conceptual factors. In contrast, our goal is to identify when and how infants recruit their conceptual knowledge in the process of word-learning. As will be discussed momentarily, we have generated considerable evidence in pursuit of this goal, documenting the ways in which conceptual information permeates word-learning from infancy onward (Booth & Waxman, 2002a, 2002b; Booth et al., 2005).

Continuity over development. Finally, our perspectives differ on the question of continuity over development. Although the ALA fundamentally rests on basic attentional and perceptual processes that operate continuously throughout development, the account also posits two kinds of discontinuity. First, the ALA suggests that the process of word-learning is initially unconstrained. Only after infants have amassed a sufficiently large (productive) vocabulary from which to detect a correlation between nouns and shape-based commonalities does the very first constraint (i.e., the shape bias) come on line (Smith, 1995, 1999). The ALA also suggests that the process of word-learning initially operates over perceptual and linguistic information alone. Only relatively late in acquisition does conceptual information exert any influence. In contrast, we see considerable continuity in both of these aspects of development. As noted in the preceding sections, we have argued that word-learning is constrained from the time infants produce their very first words, and that conceptual information guides the process of acquisition throughout. These fundamental differences between our perspective and that of the ALA inspired our initial interest in the phenomenon known as the *shape bias*.
Points of compatibility with the ALA.

To be clear, our interest in the shape bias was never motivated by any quarrel over the importance of perceptual information. We have no doubt that infants' perceptual

capacities are crucial to both lexical and conceptual development. In our view, infants' sensory-perceptual systems determine, at least in part, which aspects of the input they will be sensitive to and how they are interpreted. Neither were we motivated by any quarrel over the importance of attentional processes in lexical and conceptual development. We appreciate infants' attentional biases, and recognize that these biases interact with each other on a moment-by-moment basis and evolve over time. We also were not motivated by any quarrel over the power of associative learning in development. We have noted that infants' impressive ability to detect statistical regularities supports their discovery of linguistic and conceptual units (Aslin et al., 1999; Gomez & Maye, 2005; Murphy, 2004; Quinn & Johnson, 2000; Saffran, 2003; Younger, 1990). Indeed, we appeal to these very abilities in describing the developmental phenomena underlying our own work (Booth & Waxman, 2003b; Waxman, 2002b; Waxman & Lidz, 2006). Finally, we did not set out to show that conceptual knowledge is represented in a fixed and unitary manner, or that infants recruit these representations consciously or deliberately in the process of word-learning (as implied by Colunga & Smith, 2004; Smith, Jones, Yoshida, & Colunga, 2003; Smith & Samuelson, in press).

Resolving a puzzle

Instead, our investigations were designed to resolve a puzzle. On the one hand, the developmental literature revealed abundant evidence that conceptual knowledge is available early enough to guide word learning from the outset. On the other hand, proponents of the ALA claimed that early word-learning is impervious to conceptual information and is guided instead by attentional biases that are triggered directly and automatically by perceptual (and linguistic) inputs (e.g., Colunga & Smith, 2004; Landau, Smith, & Jones, 1998; Smith, 1995, 1999; Smith, Jones, & Landau, 1996; Smith et al., 2003).

Our targeted empirical contribution

We took as our empirical starting point the hypothesis that word-learning (including the shape bias) is influenced not only by perceptual, but also by conceptual information. In our first studies (Booth & Waxman, 2002b), we targeted 3-year-olds because at this point, children demonstrate a clear shape bias in word-learning (that is, noun-learning). Our goal was to question the claim that children's patterns of word

extension were mediated wholly by the perceptual properties (e.g., eyes) of the objects being labeled (Jones, Smith, & Landau, 1991; Landau, Smith, & Jones, 1988). Following the ALA methods closely, we introduced a novel target object, labeled it with a novel count noun, and examined children's extension of that noun to a series of test objects which matched the target along one of three perceptual dimensions (shape, size, and texture). Importantly, however, we modified the original procedure by introducing each target object within the context of a short vignette. Children assigned to the Animate condition heard vignettes describing the targets as animate objects (e.g., "...has a mommy and daddy who love it very much"); those in the Artifact condition heard the same targets described as artifacts (e.g., "...was made by an astronaut to do a special job on her spaceship"). By exposing children in both conditions to the same target objects named with the same novel nouns, we effectively held constant the perceptual properties of the objects, while manipulating their conceptual status as animate kinds or artifacts. We reasoned that if conceptual information (provided in the vignettes) permeates word-learning, then children in the Artifact condition would extend novel nouns primarily on the basis of shape, but that those in the Animate condition would extend on the basis of both shape and texture. This prediction was supported. Three-year-olds' noun extensions differed systematically as a function of the conceptual information provided in the vignettes.

We then went on to explore the developmental antecedents of this phenomenon. We adapted our task to accommodate 18- to 22-month-old infants. Like three-year-olds, infants extended novel nouns differently as a function of the conceptual information (animate vs. artifact) that we provided in the vignettes.

Competing interpretations of our results

Our interpretation. In our view, these results are incompatible with the ALA (Booth & Waxman, 2002b, 2003a). First, proponents of the ALA have claimed that a shape bias does not emerge until children have amassed a minimum of between 50 and 150 nouns in their productive vocabulary (Gershkoff-Stowe & Smith, 2004; Jones & Smith, 2002; Samuelson & Smith, 1999; Smith, 1999). Our evidence challenges this claim: Booth et al.'s 18- to 22-month-olds boasted a mean productive vocabulary of only 18 count nouns, yet they extended novel words on the basis of shape. Thus, well before

they produce 50 nouns, infants harbor clear expectations when mapping words (nouns) to meaning (also see Booth et al., 2005; Graham & Poulin-Dubois, 1999).

Second, and relatedly, proponents of the ALA have argued that word-learning is impervious to conceptual information (e.g., Jones et al., 1991; Landau et al., 1998; Smith et al., 1996). Our results challenge this claim: Booth et al.'s 18- to 22-month-olds were influenced by the information provided in the vignettes. Moreover, infants' extensions of novel words were more systematic in the animate than in the artifact condition. This finding fits well with evidence that infants' early sensitivities to both perceptual and conceptual information (e.g., faces, biological motion, agency, and intentionality) support the rapid acquisition of knowledge about animate kinds (Bertenthal, 1993; Carey, 1995; R. Gelman, Durgin, & Kaufman, 1995; Mandler & McDonough, 1998; Rakison & Poulin-Dubois, 2001; Spelke, Phillips, & Woodward, 1995; Turati, 2004; Woodward, 1998). Although infants' conceptual knowledge about animate objects is rudimentary in comparison to that of an older child or adult, our results reveal that this conceptual knowledge, however rudimentary, is brought to bear in infants' word-learning.

Our results and interpretation are fortified by a number of additional studies (e.g., Diesendruck, Markson, & Bloom, 2003; S. A. Gelman & Bloom, 2000; Gutheil, Bloom, Valderrama, & Freedman, 2004; Keil, 1994; Kemler Nelson, 1995; Lavin & Hall, 2001; Soja, Carey, & Spelke, 1991; Ward, Becker, Hass, & Vela, 1991; Welder & Graham, 2001), including those described by Diesendruck and Bloom (2003) in their target article featured in this exchange. Diesendruck and Bloom documented that young children use an object's shape as an index of its kind. They provided clear evidence that three-year-olds were more inclined to extend category-relevant properties (e.g., 'It was made especially to play with cats') than category-irrelevant properties (e.g., 'I got this for my birthday') to objects on the basis of shape. Moreover, children's attention to shape was not restricted to naming contexts, as has been argued by the ALA. Instead, in both a naming and non-naming context, toddlers use the shape of an object (a perceptual property) as a cue to its conceptual status.

ALA's interpretation. Smith, Jones, and Colunga (Smith et al., 2003) have taken quite a different tack, claiming that the evidence we produced was, in fact, consistent with their own view. They did so by asserting that the information in our vignettes (e.g.,

“...has a mommy and daddy that love it very much...”) was not conceptual at all, but rather was ‘linguistic’ and therefore ‘perceptual’ (see also Colunga & Smith, 2004). We disagree. To be sure, our vignettes were perceptible, and infants clearly perceived (heard) the words we produced. But words are more than perceptual signatures; they are symbols whose meaning cannot be reduced to the discrete sensory experiences with which they co-occur (Bloom, 1999; Golinkoff & Hirsh-Pasek, 2000).¹ To see why this is so, consider words like ‘give’ and ‘take’. Although young children learn these words, their meaning cannot be distinguished on the basis of observation alone, since any scenario involving one necessarily involves the other (Clark, 1971; Gillette, Gleitman, Gleitman, & Lederer, 1999). In fact, for most words (e.g., ‘justice’, ‘think’, ‘phone’, ‘the’, ‘if’), the perceptual grounding is negligible at best. The same holds for the words and phrases in our vignettes. The meaning of ‘jump’ for example, cannot be reduced to an association to a perceptual experience involving an object moving vertically away from and towards a horizontal surface. Rather, ‘jump’ involves a relation between objects, generated by internal forces, often in the service of some goal. In sum, words are quintessentially symbolic; they have meanings that often go beyond perception, and make contact with conceptual knowledge (Murphy & Medin, 1985; Waxman & Lidz, 2006).

For us, this type of information is conceptual in nature. If ALA proponents choose to characterize it as ‘perceptual,’ then perhaps our differences are merely terminological. But ALA proponents imply more (Smith et al., 2003; Yoshida & Smith, 2003a). They describe conceptual knowledge as ‘...nothing more than a web of correlations, including perceptual features, words, category structure, contexts, and so on’ (Colunga & Smith, 2004, p. 31). Unless symbols, causal relations, and explanatory theories are included under ‘category structure’ or ‘so on,’ this recent characterization paints a picture of conceptual knowledge that we do not endorse. Rather, we are persuaded by evidence demonstrating that causal relations and explanatory theories cannot be reduced to a set of simple associations (see, for e.g., Ahn, Kalish, Medin, & Gelman, 1995; Fenker, Waldmann, & Holyoak, 2005; Gopnik et al., 2004; Satpute et al., 2005; Waldmann, 1996).

ALA’s targeted empirical contribution

We turn now to the evidence offered in support of the ALA. Perhaps the most notable feature of Smith et al. (2002) and Samuelson (2002) is their longitudinal training design. Both began by identifying toddlers who should be too young and/or linguistically experienced to reveal a shape bias in the standard word-extension task. These toddlers were then trained over several weeks on a handful of nouns paired with objects that shared a common shape (i.e., shape-based categories). At the end of training, toddlers were introduced to a new set of novel nouns paired with new sets of objects. The results indicated that toddlers in the experimental condition (but not those in a series of control conditions) extended these novel nouns systematically on the basis of shape. Moreover, parental reports (MCDI) suggested that during the course of the longitudinal study, the lexical development (outside the laboratory) of toddlers in the experimental condition was accelerated relative to that of toddlers in the control conditions.

Interpretations of the targeted ALA results

Smith et al. (2002) and Samuelson (2002) interpreted this result as evidence that with training, toddlers can successfully detect correlations between novel nouns and shape-based commonalities (over a surprisingly small data set!) and can generalize what they have learned to new instances. We take no issue with this interpretation. However, we do not see it as evidence favoring the ALA, but rather as equally consistent with the positions articulated by us (Booth et al., 2006) and by Diesendruck and Bloom (2003).

Although toddlers were clearly able to detect the correlations between nouns and shape that Smith et al. (2002) and Samuelson (2002) presented during training, there are at least two compelling reasons to suspect that this association is not the only mechanism underlying their performance. First, there is considerable evidence suggesting that by the time they entered the training studies, toddlers had already established a link between count nouns and object categories (Booth & Waxman, 2002a, 2003b; Waxman, 1999; Waxman & Booth, 2001, 2003; Waxman & Hall, 1993; Waxman & Markow, 1995, 1998). Second, evidence suggests that during this same developmental time frame, count nouns come to have inductive force for infants, beckoning them to look beyond perceptible properties of objects for hidden, perhaps causal, commonalities among them (Booth & Waxman, 2002a; Diesendruck & Bloom, 2003; S. A. Gelman & Kalish, in press; Graham, Kilbreath, & Welder, 2004; Welder & Graham, 2001).

If this is the case, then what might have been the impact of the training provided by Smith et al. (2002) and Samuelson (2002)? We suspect that its impact was two-pronged. First, providing names for the novel categories led infants to construe them as kinds with more in common than perceptual likeness alone. Second, the highly constrained properties of the training objects highlighted the relevance of shape as a reliable cue to those kinds (Diesendruck, 2003 #8598; Bloom, 2000 #482}. This raises the possibility that training infants on relations between shape and other reliable indicators of kind should also facilitate the emergence of a shape-bias.

We have recently begun to test this possibility. We have focused specifically on object function as an alternative marker of kind because we have previously demonstrated that object functions, like object names, highlight categories for infants (Booth & Waxman, 2002a). Moreover, because object functions are often causally related to object shape, they can provide a basis for understanding *why* shape is a good cue to artifact categories. Infants as young as 18 months of age appear to be sensitive to the causal relation between shape and function, and can use this relation to form new categories (Booth, 2006; Kemler Nelson, 1999). To test whether they can also capitalize on this sensitivity in developing a shape bias, Ware (in press) used Smith et al.'s (2002) longitudinal design, but provided toddlers with object functions, instead of names, during training. If, as we have suggested, the effect of training in Smith et al. (2002) and Samuelson (2002) was to reinforce the importance of shape as an indicator of kind, then object functions that are causally related to object shape should be at least as effective as count nouns in inducing a shape bias. Evidence suggests that this is in fact the case (Ware, in press).

In her target article, Samuelson (2002) considers the sources of information that toddlers recruit in learning words to describe, not only objects, but also non-solid substances. Like Smith et al. (2002), Samuelson (2002) interprets her longitudinal data as evidence for the ALA. She demonstrates that toddlers tend to extend novel words applied to non-solid substances on the basis of shape. In her view, the source of toddlers' error is their learning history. Consistent with the ALA, she suggests that toddlers build up a shape bias as they become sensitive to regularities in their own lexicons, specifically to the correlation between count nouns and object shape. In her view, toddlers apply this

shape-bias in an overly general fashion, and that as a result, they attend to shape in learning words for both solid and (erroneously) to non-solid substances. What she is proposing is in fact a classic example of rule generalization. Nonetheless, there are reasons to question the assumptions upon which her argument is based.

First, we suspect that toddlers' knowledge about non-solid substances lags behind that of solid objects. Although infants appear to appreciate a fundamental distinction between solid and non-solid substances within the first year of life (Huntley-Fenner, Carey, & Solimando, 2002; Soja, Carey, & Spelke, 1993), they may acquire knowledge about solid objects more rapidly than about non-solid substances. After all, distinctions within the class of non-solid substances are not strongly supported by their perceptual features. For example, glue and shampoo are very similar in their consistency; it may take some time to notice that they are fundamentally different kinds of substances that engender very different outcomes. If this is the case, toddlers in the training study may have focused on shape because they had not yet developed clear expectations about non-solid substances.

Moreover Samuelson's (2002) training procedures appear to incorporate a design feature that could have inadvertently drawn toddlers' attention toward shape in the non-solid test trials. During the longitudinal training period, toddlers were regularly familiarized with the forced-choice task that would be used at test. On each of these occasions, the experimenter applied a familiar noun to a familiar target object, and then asked toddlers which of two test objects could also be named by that noun. However, it appears that toddlers were exposed to solid objects only on these familiar name generalization trials. It is not unreasonable to assume that this training attracted attention to shape matches across all tests.

Conclusions

Remaining challenges for the ALA. Taken together, the evidence under consideration in this special section is consistent with an inclusive view of word-learning. As infants and young children establish word meanings, they draw upon their linguistic, conceptual, and perceptual capacities and on the relations among these. We endorse this view, and we read Diesendruck and Bloom (2003) as endorsing it as well. Is the evidence

also consistent with the attentional learning account? Are simple associative processes at the heart of the development of the lexicon in general, and the shape bias in particular?

The answer to this question depends crucially on how the ALA interprets the information that we consider to have conceptual content (e.g., our vignettes). As already noted, proponents of this account have claimed that this information is actually ‘perceptual.’ If there were independent evidence that conceptual information is identical to perceptual information in terms of representation and process, and that conceptual information is nothing more than bits of information over which correlations can be detected, then perhaps the core assertions of the ALA might be saved. But if conceptual information amounts to something more, including, for example, attention to causal relations and explanatory theories, and if these relations and theories promote attention to some correlations over others, then the ALA as currently formulated is inadequate (Ahn et al., 1995; Fenker et al., 2005; Gopnik et al., 2004; Satpute et al., 2005; Waldmann, 1996). Perhaps an associationist account of how such conceptual information is represented is possible, but such an account has yet to be adequately specified (see Rogers & McClelland, 2005; Yoshida & Smith, 2003b; 2003c for recent attempts).

Another persisting challenge will be to clarify the ALA position relative to the evidence. First, in the most recent formulations of the ALA, the emergence of the shape bias is tied to infants’ own productive vocabulary. Why then do 18- to 22-month-old infants in our experiments, boasting a mean productive vocabulary of only 18 words, show a shape bias (Booth et al., 2005)? Second, according to the ALA, the shape bias is purely a lexical phenomenon. Why then do young children attend to shape in both lexical and non-lexical categorization tasks (Diesendruck & Bloom, 2003; Samuelson & Smith, 2005)? Third, the current formulation of the ALA asserts that the simple associative learning system is encapsulated from conceptual information. Why then does information concerning the ontological status of objects (in our vignettes) affect how their names are extended (Booth & Waxman, 2002b; Booth et al., 2005)?

Perhaps in response to these challenges, proponents of ALA will concede that infants attend to correlations between among perceptual, linguistic, *and* ‘conceptual’ information; perhaps they will agree that these correlations permit infants to develop expectations that guide the formation of new categories (lexicalized or not). However,

such a concession would reduce the ALA to an unconstrained correlational mechanism, one that offers no principled account of how learners make headway in solving the intractable problem of word-learning. Most importantly, this would leave unanswered the crucial question of how infants sift through vast amounts of information available to detect just those units and relations that will support the acquisition of knowledge about objects, events, and relations in the world, and the words we use to describe them.

Articulating constraints on acquisition. In our view, the explanatory power of a developmental theory depends importantly upon its articulation of the filters or constraints that guide acquisition. Whether development involves detecting simple correlations, extracting causal relations, and/or developing theories, the developmental process could never get off the ground without some such guiding forces in place (Carey & Gelman, 1991; Elman, Bates, Johnson, Karmiloff-Smith, & et al., 1996; R. Gelman & Williams, 1998; Keil, 1990; Medin et al., 1990; Murphy & Medin, 1985; Rakison, 2003). One advantage of connectionist models is that they force theorists to be explicit about such constraints (e.g. Munakata, 2006). Unfortunately, however, all too often the constraints built into these models make little contact with psychological processes. Connectionist modeling is a tool the ALA proponents have used admirably. But it is a mischaracterization to describe these models (or children) as ‘simple unbiased learner[s] of statistical regularities’ (Samuelson, 2002, p. 18). This is misleading precisely because it ignores the fact that constraints have in fact been built into the system, either explicitly (in the permissible computations themselves) or implicitly (in the selection of the precise stimuli that will serve as input upon which the system will ‘learn’) (Elman et al., 1996).

A review of current theoretical, empirical and modeling approaches suggests a number of constraints that are relevant to the development of word-learning in general, and to the expression of a shape bias for solid objects in particular (Woodward, 2000). Some are perceptually-based (e.g., attention to shape (Biederman, 1987; Marr, 1978; Strauss & Cohen, 1980; Wilcox, 1999) or human speech (Vouloumanos & Werker, 2004; Werker & Fennell, 2004)). Others go beyond perception, hinging on causal information (e.g., attention to function or intention) (Akhtar & Tomasello, 2000; Booth, 2006; Booth & Waxman, 2002a; Gopnik et al., 2004; Woodward, 1998). Our own view is that there are also knowledge-based constraints that influence word meaning in a top-down fashion.

We have demonstrated that this is the case for the acquisition of words for animate kinds, and others have done so for the acquisition of non-solid material kinds and foods (Carey, 1990; Keil, 1991; Lavin & Hall, 2001).

A persisting developmental goal. As in the past, it will continue to be our goal to specify the constraints that permit the (otherwise intractable) process of lexical and conceptual development to get off the ground, and to trace the evolution of these constraints over the course of early development. We have made significant progress towards this goal by demonstrating that 1) by the time they cross the threshold into word-learning, infants harbor a broad expectation linking words to commonalities among objects (Balaban & Waxman, 1997; Waxman & Booth, 2003), 2) this initially broad expectation is fine-tuned over the subsequent year to reflect specific relations between grammatical forms and types of meaning (Booth & Waxman, 2003b; Waxman, 1999; Waxman & Booth, 2001; Waxman & Markow, 1995, 1998), and 3) conceptual, linguistic, and perceptual sources of information influence one another powerfully and continuously in the service of word-learning throughout infancy and early childhood (Booth & Waxman, 2002a, 2002b; Booth et al., 2005).

Footnotes

¹ As a result, we are unsurprised by recent data (Colunga & Smith, 2004) showing that 3-year-olds' word extensions were also affected by hearing a disconnected list of the content words that were pulled from our vignettes. In our view, children do so because they are influenced by the *meaning* of these words. Although presenting the words in narrative context likely facilitates access to these meanings, presenting them in isolation does not divorce the words from their meanings.

References

- Ahn, W.-k., Kalish, C. W., Medin, D. L., & Gelman, S. A. (1995). The role of covariation versus mechanism information in causal attribution. *Cognition*, *54*(3), 299-352.
- Akhtar, N., & Tomasello, M. (2000). The social nature of words and their meaning. In R. M. Golinkoff, K. Hirsh-Pasek, L. Bloom, L. B. Smith, A. L. Woodward, N. Akhtar, M. Tomasello & G. Hollich (Eds.), *Becoming a word learner: A debate on lexical acquisition* (pp. 115-135). New York, NY, US: Oxford University Press.
- Aslin, R. N., Saffran, J. R., & Newport, E. L. (1999). Statistical learning in linguistic and nonlinguistic domains. In B. MacWhinney (Ed.), *The emergence of language* (pp. 359-380). Mahwah, NJ, USA: Lawrence Erlbaum Associates, Inc., Publishers.
- Baillargeon, R. (2002). The acquisition of physical knowledge in infancy: A summary in eight lessons. In U. Goswami (Ed.), *Goswami, Usha (Ed). Inst of Child Health; U Coll London Medical School. (2002). Blackwell handbook of childhood cognitive development. Blackwell handbooks of developmental psychology.* (pp. 47-83). Malden, MA: Blackwell Publishers.
- Balaban, M. T., & Waxman, S. R. (1997). Do words facilitate object categorization in 9-month-old infants? *Journal of Experimental Child Psychology*, *64*(1), 3-26.
- Bertenthal, B. I. (1993). Infants' perception of biomechanical motions: Intrinsic image and knowledge-based constraints. In C. Granrud (Ed.), *Visual perception and cognition in infancy. Carnegie Mellon symposia on cognition* (pp. 175-214). Hillsdale, NJ, USA: Lawrence Erlbaum Associates, Inc.
- Biederman, I. (1987). Recognition-by-components: A theory of human image understanding. *Psychological Review*, *94*(2), 115-117.
- Bloom, P. (1999). Theories of word learning: Rationalist alternatives to associationism. In W. C. Ritchie (Ed.), *Handbook of child language acquisition* (pp. 249-278). San Diego: Academic Press.
- Bloom, P. (2000). *How children learn the meanings of words*. Cambridge, MA, US: The MIT Press.
- Booth, A. E. (2006). Object function and categorization in infancy: Two mechanisms of facilitation. *Infancy*, *10*(2), 145-169.
- Booth, A. E., & Waxman, S. R. (2002a). Object names and object functions serve as cues to categories for infants. *Developmental Psychology*, *38*(6), 948-957.
- Booth, A. E., & Waxman, S. R. (2002b). Word learning is 'smart': Evidence that conceptual information affects preschoolers' extension of novel words. *Cognition*, *84*(1), B11-B22.
- Booth, A. E., & Waxman, S. R. (2003a). Bringing theories of word learning in line with the evidence. *Cognition*, *87*(3), 215-218.
- Booth, A. E., & Waxman, S. R. (2003b). Mapping Words to the World in Infancy: Infants' Expectations for Count Nouns and Adjectives. *Journal of Cognition & Development*, *4*(3), 357-381.
- Booth, A. E., Waxman, S. R., & Huang, Y. T. (2005). Conceptual Information Permeates Word Learning in Infancy. *Developmental Psychology*, *41*(3), 491-505.
- Bornstein, M. H., Cote, L. R., Maital, S., Painter, K., Park, S.-Y., Pascual, L., et al. (2004). Cross-Linguistic Analysis of Vocabulary in Young Children: Spanish,

- Dutch, French, Hebrew, Italian, Korean, and American English. *Child Development*, 75(4), 1115-1139.
- Carey, S. (1990). On some relations between the description and the explanation of developmental change. In G. Butterworth & P. Bryant (Eds.), *Causes of development: Interdisciplinary perspectives* (pp. 135-157). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Carey, S. (1995). On the origin of causal understanding. In D. P. D. Sperber (Ed.), *Causal cognition: A multidisciplinary debate. Symposia of the Fyssen Foundation* (pp. 268-308). New York, NY, USA: Clarendon Press/Oxford University Press.
- Carey, S., & Gelman, R. (Eds.). (1991). *The epigenesis of mind: Essays on biology and cognition*. Hillsdale, NJ, England: Lawrence Erlbaum Associates, Inc.
- Cimpian, A., & Markman, E. M. (2005). The Absence of a Shape Bias in Children's Word Learning. *Developmental Psychology*, 41(6), 1003-1019.
- Clark, E. V. (1971). On the acquisition of the meaning of before and after. *Journal of Verbal Learning & Verbal Behavior Vol 10(3) Jun 1971*, 266-275.
- Clark, E. V. (2004). How language acquisition builds on cognitive development. *Trends in Cognitive Sciences Vol 8(10) Oct 2004*, 472-478.
- Colunga, E., & Smith, L. B. (2004, August 4-7). *Dumb mechanisms make smart concepts*. Paper presented at the 26th Annual Conference of the Cognitive Science Society, Chicago, IL.
- Diesendruck, G., & Bloom, P. (2003). How specific is the shape bias? *Child Development*, 74(1), 168-178.
- Diesendruck, G., Markson, L., & Bloom, P. (2003). Children's reliance on creator's intent in extending names for artifacts. *Psychological Science*, 14(2), 164-168.
- Echols, C. H., & Marti, N. C. (2004). The identification of words and their meanings: From perceptual biases to language-specific cues. In D. G. Hall & S. R. Waxman (Eds.), *Weaving a Lexicon* (pp. 41-78). Cambridge, MA: The MIT Press.
- Elman, J. L., Bates, E. A., Johnson, M. H., Karmiloff-Smith, A., & et al. (1996). *Rethinking innateness: A connectionist perspective on development*. Cambridge, MA, USA: Mit Press.
- Fenker, D. B., Waldmann, M. R., & Holyoak, K. J. (2005). Accessing causal relations in semantic memory. *Memory & Cognition*, 33(6), 1036-1046.
- Gelman, R. (1990). First principles organize attention to and learning about relevant data: Number and the animaten/animate distinction as examples. *Cognitive Science*, 14(1), 79-106.
- Gelman, R., Durgin, F., & Kaufman, L. (1995). Distinguishing between animates and inanimates: Not by motion alone. In D. P. D. Sperber (Ed.), *Causal cognition: A multidisciplinary debate. Symposia of the Fyssen Foundation* (pp. 150-184). New York, NY, US: Clarendon Press/Oxford University Press.
- Gelman, R., & Williams, E. M. (1998). *Enabling constraints for cognitive development and learning: Domain specificity and epigenesis*. Damon, William (Ed). (1998). Handbook of child psychology: Volume 2: Cognition, perception, and language.
- Gelman, S. A., & Bloom, P. (2000). Young children are sensitive to how an object was created when deciding what to name it. *Cognition*, 76(2), 91-103.
- Gelman, S. A., & Coley, J. D. (1991). Language and categorization: The acquisition of natural kind terms. In S. A. B. J. P. Gelman (Ed.), *Perspectives on language and*

- thought: Interrelations in development* (pp. 146-196). New York, NY, USA: Cambridge University Press.
- Gelman, S. A., & Diesendruck, G. (1999). What's in a concept? Context, variability, and psychological essentialism. In I. E. Sigel (Ed.), *Development of mental representation: Theories and applications* (pp. 87-111). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.
- Gelman, S. A., & Kalish, C. (in press). In D. Kuhn & R. Siegler (Eds.), *Handbook of Child Psychology* (6 ed., Vol. 2).
- Gershkoff-Stowe, L., & Smith, L. B. (2004). Shape and the First Hundred Nouns. *Child Development, 75*(4), 1098-1114.
- Gillette, J., Gleitman, H., Gleitman, L., & Lederer, A. (1999). Human simulations of vocabulary learning. *Cognition, 73*(2), 135-176.
- Golinkoff, R. M., & Hirsh-Pasek, K. (2000). Word learning: Icon, Index, or Symbol? In R. M. Golinkoff, K. Hirsh-Pasek, L. Bloom, L. B. Smith, A. L. Woodward, N. Akhtar, M. Tomasello & G. Hollich (Eds.), *Becoming a word learner: A debate on lexical acquisition* (pp. 3-18). New York, NY, US: Oxford University Press.
- Golinkoff, R. M., Hirsh-Pasek, K., Bloom, L., Smith, L. B., Woodward, A. L., Akhtar, N., et al. (2000). *Becoming a word learner: A debate on lexical acquisition*. New York, NY, US: Oxford University Press.
- Gomez, R., & Maye, J. (2005). The Developmental Trajectory of Nonadjacent Dependency Learning. *Infancy, 7*(2), 183-206.
- Gopnik, A., Glymour, C., Sobel, D. M., Schulz, L. E., Kushnir, T., & Danks, D. (2004). A Theory of Causal Learning in Children: Causal Maps and Bayes Nets. *Psychological Review, 111*(1), 3-32.
- Graham, S. A., Kilbreath, C. S., & Welder, A. N. (2004). Thirteen-Month-Olds Rely on Shared Labels and Shape Similarity for Inductive Inferences. *Child Development, 75*(2), 409-427.
- Graham, S. A., & Poulin-Dubois, D. (1999). Infants' reliance on shape to generalize novel labels to animate and inanimate objects. *Journal of Child Language, 26*(2), 295-320.
- Gutheil, G., Bloom, P., Valderrama, N., & Freedman, R. (2004). The role of historical intuitions in children's and adults' naming of artifacts. *Cognition, 91*(1), 23-42.
- Hirsh-Pasek, K., Golinkoff, M., & Hollich, G. (2000). An emergentist coalition model for word learning: Mapping words to objects is a product of the interaction of multiple cues. In R. M. Golinkoff, K. Hirsh-Pasek, L. Bloom, L. B. Smith, A. L. Woodward, N. Akhtar, M. Tomasello & G. Hollich (Eds.), *Becoming a word learner: A debate on lexical acquisition* (pp. 136-164). New York, NY, US: Oxford University Press.
- Hoff, E., & Naigles, L. (2002). How children use input to acquire a lexicon. *Child Development, 73*(2), 418-433.
- Hollich, G. J., Hirsh-Pasek, K., Golinkoff, R. M., Brand, R. J., Brown, E., Chung, H. L., et al. (2000). Breaking the language barrier: An emergentist coalition model for the origins of word learning. *Monographs of the Society for Research in Child Development, 65*(3), v-123.

- Huntley-Fenner, G., Carey, S., & Solimando, A. (2002). Objects are individuals but stuff doesn't count: Perceived rigidity and cohesiveness influence infants' representations of small groups of discrete entities. *Cognition*, 85(3), 203-221.
- Huttenlocher, J., Vasilyeva, M., Cymerman, E., & Levine, S. (2002). Language input and child syntax. *Cognitive Psychology*, 45(3), 337-374.
- Jones, S. S., & Smith, L. B. (2002). How children know the relevant properties for generalizing object names. *Developmental Science*, 5, 219-232.
- Jones, S. S., Smith, L. B., & Landau, B. (1991). Object properties and knowledge in early lexical learning. *Child Development*, 62(3), 499-516.
- Keil, F. C. (1990). Constraints on the acquisition and representation of knowledge. In Keil, F. C. (1991). The emergence of theoretical beliefs as constraints on concepts. In Keil, F. C. (1994). Explanation, association, and the acquisition of word meaning. *Lingua*, 92, 169-196.
- Kemler Nelson, D. G. (1995). Principle-based inferences in young children's categorization: Revisiting the impact of function on the naming of artifacts. *Cognitive Development*, 10(3), 347-380.
- Kemler Nelson, D. G. (1999). Attention to functional properties in toddlers' naming and problem-solving. *Cognitive Development*, 14(1), 77-100.
- Landau, B., Smith, L., & Jones, S. (1998). Object shape, object function, and object name. *Journal of Memory & Language*, 38(1), 1-27.
- Landau, B., Smith, L. B., & Jones, S. S. (1988). The importance of shape in early lexical learning. *Cognitive Development*, 3(3), 299-321.
- Lavin, T. A., & Hall, D. G. (2001). Domain effects in lexical development: Learning words for foods and toys. *Cognitive Development*, 16(4), 929-950.
- Mandler, J. M. (1988). How to build a baby: On the development of an accessible representational system. *Cognitive Development*, 3(2), 113-136.
- Mandler, J. M., & McDonough, L. (1998). On developing a knowledge base in infancy. *Developmental Psychology*, 34(6), 1274-1288.
- Markman, E. M., Wasow, J. L., & Hansen, M. B. (2003). Use of the mutual exclusivity assumption by young word learners. *Cognitive Psychology*, 47(3), 241-275.
- Marr, D. N., H.K. (1978). Representation and recognition of the spatial organization of three-dimensional shapes. *Proceedings of the Royal Society of London. Series B, Biological Sciences*, 200(1140), 269-294.
- Medin, D. L., Ahn, W.-k., Bettger, J., Florian, J., Goldstone, R., Lassaline, M., et al. (1990). Safe takoffs--soft landings. *Cognitive Science*, 14(1), 169-178.
- Mintz, T. H. (2005). Linguistic and Conceptual Influences on Adjective Acquisition in 24- and 36-Month-Olds. *Developmental Psychology*, 41(1), 17-29.
- Mintz, T. H., & Gleitman, L. R. (2002). Adjectives really do modify nouns: The incremental and restricted nature of early adjective acquisition. *Cognition*, 84(3), 267-293.
- Munakata, Y. (2006). Information processing approaches to development. In W. Damon, R. Lerner, D. Kuhn & R. Siegler (Eds.), *Handbook of Child Psychology* (6 ed., Vol. 2). Hoboken, NJ: John Wiley & Sons, Inc.
- Murphy, G. L. (2004). Concepts in Infancy. In *The Big Book of Concepts* (pp. 271-315). Cambridge, MA: The MIT Press.

- Murphy, G. L., & Medin, D. L. (1985). The role of theories in conceptual coherence. *Psychological Review*, 92(3), 289-316.
- Quinn, P. C., & Johnson, M. H. (2000). Global-before-basic object categorization in connectionist networks and 2-month-old infants. *Infancy*, 1(1), 31-46.
- Rakison, D. H. (2003). Free association? Why category development requires something more. *Developmental Science*, 6(1), 20-22.
- Rakison, D. H., & Poulin-Dubois, D. (2001). Developmental origin of the animate-inanimate distinction. *Psychological Bulletin*, 127(2), 209-228.
- Rogers, T. T., & McClelland, J. L. (2005). A parallel distributed processing approach to semantic cognition: Applications to conceptual development. In L. Gershkoff-Stowe & D. H. Rakison (Eds.), *Building object categories in developmental time* (pp. 335-387). Mahwah, NJ: Lawrence Erlbaum Associates.
- Saffran, J. R. (2003). Statistical language learning: Mechanisms and constraints. *Current Directions in Psychological Science*, 12(4), 110-114.
- Samuelson, L. K. (2002). Statistical regularities in vocabulary guide language acquisition in connectionist models and 15-20-month-olds. *Developmental Psychology*, 38(6), 1016-1037.
- Samuelson, L. K., & Smith, L. B. (1999). Early noun vocabularies: Do ontology, category structure and syntax correspond? *Cognition*, 73(1), 1-33.
- Samuelson, L. K., & Smith, L. B. (2005). They call it like they see it: Spontaneous naming and attention to shape. *Developmental Science*, 8(2), 182-198.
- Satpute, A. B., Fenker, D. B., Waldmann, M. R., Tabibnia, G., Holyoak, K. J., & Lieberman, M. D. (2005). An fMRI study of causal judgments. *European Journal of Neuroscience Vol 22(5) Sep 2005*, 1233-1238.
- Smith, L. B. (1995). Self-organizing processes in learning to learn words: Development is not induction. In C. A. Nelson (Ed.), *Basic and applied perspectives on learning, cognition, and development. The Minnesota Symposia on Child Psychology* (Vol. 28, pp. 1-32). Mahwah, NJ, USA: Lawrence Erlbaum Associates, Inc.
- Smith, L. B. (1999). Children's noun learning: How general learning processes make specialized learning mechanisms. In B. MacWhinney (Ed.), *The emergence of language* (pp. 277-303). Mahwah, NJ, USA: Lawrence Erlbaum Associates, Inc., Publishers.
- Smith, L. B., Jones, S. S., & Landau, B. (1996). Naming in young children: A dumb attentional mechanism? *Cognition*, 60(2), 143-171.
- Smith, L. B., Jones, S. S., Landau, B., Gershkoff-Stowe, L., & Samuelson, L. K. (2002). Object name learning provides on-the-job training for attention. *Psychological Science*, 13(1), 13-19.
- Smith, L. B., Jones, S. S., Yoshida, H., & Colunga, E. (2003). Whose DAM account? Attentional learning explains Booth and Waxman. *Cognition*, 87(3), 209-213.
- Smith, L. B., & Samuelson, L. (in press). An attentional learning account of the shape bias: Reply to Cimplied & Markman (2005) and Booth, Waxman & Huang (2005). *Developmental Psychology*.
- Soja, N. N., Carey, S., & Spelke, E. S. (1991). Ontological categories guide young children's inductions of word meaning: Object terms and substance terms. *Cognition*, 38(2), 179-211.

- Soja, N. N., Carey, S., & Spelke, E. S. (1993). *Ontological categories guide young children's inductions of word meaning*: Goldman, Alvin I (Ed).
- Spelke, E. S. (1994). Initial knowledge: Six suggestions. *Cognition*, 50(1-3), 431-445.
- Spelke, E. S., Phillips, A., & Woodward, A. L. (1995). Infants' knowledge of object motion and human action. In D. P. D. Sperber (Ed.), *Causal cognition: A multidisciplinary debate. Symposia of the Fyssen Foundation* (pp. 44-78). New York, NY, US: Clarendon Press/Oxford University Press.
- Strauss, M., & Cohen, L. B. (1980). *Infant immediate and delayed memory for perceptual dimensions*. Paper presented at the International Conference on Infancy Studies, New Haven, CT.
- Tomasello, M., & Akhtar, N. (2003). What paradox? A response to Naigles (2002). *Cognition*, 88(3), 317-323.
- Turati, C. (2004). Why Faces Are Not Special to Newborns: An Alternative Account of the Face Preference. *Current Directions in Psychological Science*, 13(1), 5-8.
- Vouloumanos, A., & Werker, J. F. (2004). Tuned to the signal: The privileged status of speech for young infants. *Developmental Science*, 7(3), 270-276.
- Waldmann, M. R. (1996). *Knowledge-based causal induction*: Shanks, David R (Ed); Holyoak, Keith (Ed); Medin, Douglas L (Ed).
- Ward, T. B., Becker, A. H., Hass, S. D., & Vela, E. (1991). Attribute availability and the shape bias in children's category generalization. *Cognitive Development*, 6(2), 143-167.
- Ware, E. (in press). Form follows function: The role of artifact function in the development of the shape bias. *Dissertation Abstracts International*.
- Waxman, S. R. (1998). Linking object categorization and naming: Early expectations and the shaping role of language. [References]. In D. L. Medin (Ed.), *The psychology of learning and motivation: Advances in research and theory, Vol 38* (pp. 249-291). San Diego, CA: Academic Press.
- Waxman, S. R. (1999). Specifying the scope of 13-month-olds' expectations for novel words. *Cognition*, 70(3), B35-B50.
- Waxman, S. R. (2002a). Early word learning and conceptual development: Everything had a name, and each name gave birth to a new thought. In U. Goswami (Ed.), *Blackwell handbook of childhood cognitive development* (pp. 102-126). Oxford UK: Blackwell Publishers.
- Waxman, S. R. (2002b). Early word-learning and conceptual development: Everything had a name, and each name gave birth to a new thought. In *Goswami, Usha (Ed) Inst of Child Health; U Coll London Medical School (2002) Blackwell handbook of childhood cognitive development Blackwell handbooks of developmental psychology* (pp. 102-126). Malden, MA: Blackwell Publishers.
- Waxman, S. R., & Booth, A. E. (2001). Seeing pink elephants: Fourteen-month-olds' interpretations of novel nouns and adjectives. *Cognitive Psychology*, 43(3), 217-242.
- Waxman, S. R., & Booth, A. E. (2003). The origins and evolution of links between word learning and conceptual organization: New evidence from 11-month-olds. *Developmental Science*, 6(2), 128-135.

- Waxman, S. R., & Braun, I. (2005). Consistent (but not variable) names as invitations to form object categories: new evidence from 12-month-old infants. *Cognition*, 95(3), B59-B68.
- Waxman, S. R., & Hall, D. G. (1993). The development of a linkage between count nouns and object categories: Evidence from fifteen- to twenty-one-month-old infants. *Child Development*, 64(4), 1224-1241.
- Waxman, S. R., & Lidz, J. (2006). Early word learning. In D. Kuhn & R. Siegler (Eds.), *Handbook of Child Psychology* (6 ed., Vol. 2). Hoboken, NJ: Wiley.
- Waxman, S. R., Lidz, J., Braun, I., & Lavin, T. A. (under review).
- Waxman, S. R., & Markow, D. B. (1995). Words as invitations to form categories: Evidence from 12- to 13-month-old infants. *Cognitive Psychology*, 29(3), 257-302.
- Waxman, S. R., & Markow, D. B. (1998). Object properties and object kind: Twenty-one-month-old infants' extension of novel adjectives. *Child Development*, 69(5), 1313-1329.
- Welder, A. N., & Graham, S. A. (2001). The influences of shape similarity and shared labels on infants' inductive inferences about nonobvious object properties. *Child Development*, 72(6), 1653-1673.
- Werker, J. F., & Fennell, C. (2004). Listening to sounds versus listening to words: Early steps in word learning. In D. G. Hall & S. R. Waxman (Eds.), *Weaving a lexicon*. (pp. 79-110). Cambridge, MA: MIT Press.
- Wilcox, T. (1999). Object individuation: Infants' use of shape, size, pattern, and color. *Cognition*, 72(2), 125-166.
- Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, 69(1), 1-34.
- Woodward, A. L. (2000). Constraining the problem space in early word learning. In R. M. Golinkoff, K. Hirsh-Pasek, L. Bloom, L. B. Smith, A. L. Woodward, N. Akhtar, M. Tomasello & G. Hollich (Eds.), *Becoming a word learner: A debate on lexical acquisition* (pp. 81-114). New York, NY, US: Oxford University Press.
- Xu, F. (1999). Object individuation and object identity in infancy: The role of spatiotemporal information, object property information, and language. *Acta Psychologica*, 102(2-3), 113-136.
- Yoshida, H., & Smith, L. B. (2003a). Known and novel noun extensions: Attention at two levels of abstraction. *Child Development*, 74(2), 564-577.
- Yoshida, H., & Smith, L. B. (2003b). Response: Correlation, concepts and cross-linguistic differences. *Developmental Science*, 6(1), 30-34.
- Yoshida, H., & Smith, L. B. (2003c). Shifting ontological boundaries: How Japanese- and English-speaking children generalize names for animals and artifacts. *Developmental Science*, 6(1), 1-17.
- Younger, B. (1990). Infants' detection of correlations among feature categories. *Child Development*, 61(3), 614-620.