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SHAPE BIAS SPECIAL SECTION

Taking stock as theories of word learning take shape

Amy E. Booth[1] and Sandra R. Waxman[2]

1. *Roxelyn and Richard Pepper Department of Communication Sciences & Disorders, Northwestern University, USA*
2. *Department of Psychology, Northwestern University, USA*

Abstract

In this paper we consider the perceptual and conceptual contributions that shape early word learning, using research on the shape bias *as a case in point. In our view, conceptual, linguistic, social-pragmatic, and perceptual sources of information influence one another powerfully and continuously in the service of word learning throughout infancy and early childhood. We articulate several key points of convergence and divergence between our theoretical perspective and that of the attentional learning account. Finally, we consider the broader implications of this debate for clarifying the forces that constrain development.*

Introduction

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, Cote, Maital, Painter, Park, Pascual, Pecheux, Ruel, Venuti & Vyt, 2004; Cimpian & Markman, 2005; Clark, 2004; S.A. Gelman & Coley, 1991; S.A. Gelman & Diesendruck, 1999; Golinkoff, Hirsh-Pasek, Bloom, Smith, Woodward, Akhtar, Tomasello & Hollich, 2000; Hirsh-Pasek, Golinkoff & Hollich, 2000; Hoff & Naigles, 2002; Hollich, Hirsh-Pasek, Golinkoff, Brand, Brown, Chung, Hennon & Rocroi, 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 attentional learning account

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

Address for correspondence: Amy Booth, Northwestern University, Roxelyn and Richard Pepper Department of Communication Sciences & Disorders, 2240 Campus Drive, Evanston, IL 60208-3540, USA; e-mail: a-booth@northwestern.edu

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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, 2002; 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 2 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, 2002; 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 below, 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, 2002; 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 deliberatively in the process of word learning (as implied by Colunga & Smith, 2004, 2008; Smith, Jones, Yoshida & Colunga, 2003; Smith & Samuelson, 2006).

Resolving a puzzle

Instead, our investigations were designed to resolve a puzzle. On the one hand, the developmental literature

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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 3-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 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 3-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.

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ALA's interpretation

Smith, Jones, Yoshida and Colunga (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, Glymour, Sobel, Schulz, Kushnir & Danks, 2004; Satpute, Fenker, Waldmann, Tabibnia, Holyoak & Lieberman, 2005; Waldmann, 1996).

[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.

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 inexperienced 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 & Waxman, 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, 2006; 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

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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 (Bloom, 2000; Diesendruck & Bloom, 2003). 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 (2007) 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, 2007).

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 *et al.*, 1991), 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).

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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; Ward, Becker, Duffin Hass & Vela, 1991)? 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 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, Parisi & Plunkett, 1996; R. Gelman & Williams, 1998; Keil, 1990; Medin, Ahn, Bettger, Florian, Goldstone, Lassaline, Markman, Rubinstein & Wisniewski, 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 & Nishihara, 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; Ward, 1993).

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).

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