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Comparison and the Development of Cognition and Language

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The last few decades have seen a rise in nativist accounts of the development of cognition and language. One reason for this is that the field of cognitive development has experienced great gains in the sophistication with which we describe human knowledge, with no corresponding gain in the sophistication of our process accounts. In particular, we argue that our field is saddled with a behaviorist view of similarity. We propose to replace this view with structure-mapping account, in which comparison is seen as a process of structural alignment and mapping.

Our main contention in this paper is that the *process of comparison* constitutes an important force by which similarity-based processes can give rise to rule-governed systems. We will begin by laying out a developmental framework that we call "the career of similarity." Then we apply this framework first to the general issue of the development of rules in learning and reasoning, and then to language learning, specifically the acquisition of word meaning.

Keywords: learning and development, analogy, relational shift

"We are far cleverer than anybody else, and that we are cries out for explanation... a good theory of the mind might reasonably be expected to say... what is about our minds that allows us, alone among all organisms, to do science." (Fodor, 1994, p. 91).

"Language is a complex, specialized skill, which develops in the child spontaneously, without conscious effort or formal instruction, is deployed without awareness of its underlying logic, is qualitatively the same in every individual, and is distinct from more general abilities to process information or behave intelligently." (Pinker, 1994, p. 18).

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Introduction

What is "so clever" about human cognition? As Vygotsky (1978) emphasized, even the cleverest of nonhuman primates is still the slave of its perceptual field, while, from an early age, humans go easily beyond what is merely perceptually available to them. What accounts for our sophisticated cognitive powers, our ability to transcend the here and now, to distance ourselves from our immediate present experience? More specifically, what accounts for our phenomenal ability to learn language, that intricate, virtually infinitely generative system, without the need for formal instruction or study?

The topic of this special issue is whether language should be conceived of as innate or learned. Our approach is to present a general learning framework that we believe can provide means of learning complex abstract systems such as language. We will argue that complex rule-governed systems like language are acquired via two main forces: first, enculturation processes, and second, a kind of "stuff and compare" process. Learners originally acquire knowledge at a highly specific level; later, comparisons amongst different exemplars promote further inferences and abstractions. Crucial to this account is the conception of comparison as a process of structural alignment and mapping, which provides a learning mechanism powerful enough to acquire rules. We will begin by laying out the framework and applying it to the general issue of the development of cognitive rules. Then we will apply these ideas to language learning, focusing chiefly on the acquisition of word meaning.

As Fodor has repeatedly pointed out (1990, pp. 201–202; 1994, pp. 90 ff), the context-independence and the abstract character of higher cognitive processes are the most characteristic and yet most puzzling features of the human mind. It has been argued that what is most characteristic of abstract cognition is its productivity, systematicity and inferential coherence (Fodor & Pylyshyn, 1988). All these features speak for the *rule*-governed nature of abstract cognition. Abstract rules — including the implicit rules that characterize human grammar — appear necessary to explain higher-order cognition (e.g., Pinker, 1994; Smith, Langston, & Nisbett, 1992).

How do we develop these abstract cognitive abilities? In the past few decades, the field of cognitive development has seen a marked increase in the sophistication of the knowledge ascribed to the developing child. But there has been no learning mechanism on offer that is powerful enough to deal with the observed phenomena. In the empiricist tradition, complex cognition was thought to evolve via experiential learning and the abstraction of early perceptual representations into abstract, rule-like mental structures. Behaviorism, the heir of empiricism in this century, proposed the mechanisms of association and stimulus generalization to explain learning. But the inability to deal with complex mental representations — or indeed, in the pure behaviorist tradition, with *any* mental representations — makes this account useless for all but the most rudimentary forms of learning. A second approach is constructivism, proposed in different forms by Piaget and Vygotsky, which postulates increasingly complex mental representations that are learned through interactions with the world — or, on Vygotsky's (1978, 1986) account, with cultural and linguistic systems. However, Piaget's global stage theory has not fared well empirically. More importantly for our purposes, although learning processes are clearly assumed in constructivism (e.g., Piaget's assimilation, accommodation and equilibration) the *mechanisms* of learning remain unspecified.

The nativist movement, we suggest, grew out of a combination of forces. First was the clear inadequacy of the available learning mechanisms to explain the development of abstract cognition, as discussed above. This inadequacy was all the clearer in the context of the Chomskian revolution through which the complexity and generativity of language, and by implication of cognitive structures in general, was brought home to cognitive researchers. Formal demonstrations of the non-learnability of language under certain assumptions (e.g., Wexler & Culicover, 1980), together with persuasive arguments that the language achievements of children far outstripped the relatively haphazard input they receive (Chomsky's "argument from the poverty of the input"), led to a further disenchantment with empiricism. A second factor was a series of impressive discoveries concerning young children's intellectual powers. The ground-breaking work of Gelman (1969; Gelman & Gallistel, 1978) on early conservation and early number concepts and of Spelke (1988, 1990) and Baillargeon (1991, in press) on infants' understanding of physical objects revealed early learning that went far beyond the capabilities of behaviorist learning models.

The confluence of these two factors, we suggest, led to the ascendance of the nativist approach, the dominant approach to the development of cognition in recent years. This approach, with roots in the Cartesian conception of the mind[1)], postulates that the human mind comes endowed with abstract representations and processing capacities. The development of higher-level cognition is thus in large part a matter of maturation or unfolding rather than of learning. For example, Spelke (1988, 1990) has argued for innate constraints that are not merely perceptual biases, but emerge from theories at the "highest level of conceptual structure". She argues for a naive theory of physical objects that gives rise to beliefs such as that objects are cohesive, bounded, and do not act on each other at a distance. R. Gelman (1990) suggests that young children are able to focus selectively in cognitive tasks because they are guided by skeletal versions of domain-specific principles (specifically, she argues for principles for counting and for reasoning about causality).

Our purpose here is to invite a reconsideration of the power of learning processes. We do not wish to argue that there is no innate component to the development of cognition and language; this is after all an empirical question. Rather, we argue that the learning account, which was rightly dismissed when the behaviorist approach was the only game in town, now deserves another look.

Our proposal seeks to bring together the theme of learning processes originating in the learner with that of cultural supports for the acquisition of complex systems. We will argue here that neither an entirely self-generated learning sequence — as proposed by the empiricists — nor an entirely culturally-provided scaffolding is sufficient to explain the development of abstract cognition. Our proposal is that the *process of comparison* is a key learning mechanism that links cultural learning — in particular language learning — with experiential learning.

The comparison process we propose is one of structural alignment and mapping. Nev-

1) Some researchers in the nativist camp might better be described as Kantians in proposing innate *a priori* schemes that give structure to empirical *a posteriori* knowledge.

ertheless, in adopting it we are embracing similarity as important in higher-order learning. Such a proposal may seem quixotic in light of a wealth of philosophical and developmental literature that casts doubt on the explanatory power of the notion of similarity, and suggests extreme caution on appeals to similarity as the basis of cognitive development. It has been argued that similarity is either irrelevant, as Goodman's (1972) in-principle arguments and Keil's (1989a) concept of "original sim" suggest, or better conceived as a deceiver, distracting children from noticing deep conceptual laws. As Quine (1969) puts it, there is little reason to think that "the muddy old notion of similarity" (p. 172) has anything to contribute to the development of abstract capacities. Others, such as Smolensky (1988) and Sloman (1996) have offered more integrative proposals in which both rule-based and similarity-based processes are involved in reasoning, problem-solving and categorization, but in very different ways. We want to go further. While we agree that the old-style similarity of classic empiricism does not provide a solution to the problem of abstraction, we contend that the *process of comparison*, viewed as an alignment or structure-mapping, constitutes an important focus of convergence of rule-governed and similarity-based processes. We will argue that similarity is best conceived of neither as a deceiver nor as a fall-back option, but rather as playing an important bootstrapping role in development (Kotovsky & Gentner, in press; Gentner & Rattermann, 1991). Before embarking on our defense of similarity in development, we survey the shape of the challenge.

The features of the abstract: can similarity account for abstract cognition?

An adequate cognitive theory must account for higher cognitive processes. But what are the features of abstract cognition? In their discussion of connectionism, Fodor & Pylyshyn (1988) emphasize three closely related properties of cognition: its *productivity*, its *systematicity*[2]*/compositionality*, and its *inferential coherence*. They argue that these features of cognition are pervasive and that they are explicable only by assuming that mental representations have internal structure. The *productivity* of our cognitive system, as evidenced by our linguistic competence and our in-principle ability to generate/understand an unbounded number of sentences, implies recursive processing. The indefinitely many representations that the system can produce must be built up by recursively combining a finite set of primitive expressions. The *systematicity/compositionality* of cognition means that the ability to produce/understand some thoughts entails the ability to produce/understand others. Thus, if a system is able to encode a representation of the form "aRb" (e.g. "John loves Mary"), then it must also be able to encode a representation of the form "bRa" (e.g. "Mary loves John"). An adequate cognitive theory must explain why we don't have punctuate cognitive capacities (such as the ca-

2) Fodor's notion of systematicity is different from Gentner's systematicity principle (discussed later), though the two are related.

pacity to represent "aRb" but not "bRa"), but rather, representational capacities that come in structurally related clusters. A related argument for the internal structure of mental representation is based on *inferential coherence*: "inferences that are of similar logical type ought, pretty generally, to elicit correspondingly similar cognitive capacities" (Fodor & Pylyshyn, 1988, p. 47). The systematicity of our reasoning abilities precludes the possibility of minds that can infer from "P & Q" to "P", but not from "Q & P" to "Q." Such highly systematic inferential abilities, some might argue, cannot be supported by the mere perception of similarities. The structure-sensitive capacity that enables us to follow inferences seems far more abstract than simple similarities between objects and scenes.

There is a fourth feature of adult cognition that seems to undermine the plausibility of similarity-based accounts. This is the *content-independence* of abstract thinking (e.g. Smith, Langston, & Nisbett, 1992). The claim is that higher-level cognitive processes operate on the logical form of mental representations, independently of their content. This is the kind of formalism that Fodor's Language of Thought hypothesis advocates (see Fodor, 1975, 1981). It is assumed that there is a sharp distinction between the abstract syntactic rules by which cognitive processes are conducted and the semantically laden representations on which these rules operate. The content-independence of abstract thinking has led to cognitive theories that postulate a set of purely syntactic "program" or "production" rules (Fong & Nisbett, 1991; Rips, 1983, 1994). In deduction theory, Rips has postulated natural-deduction rules that are sensitive only to the syntactically structured logical form of sentences, and apply no matter what the sentences happen to be about. We can, for instance, apply the rule of Universal Instantiation even to nonsense words. Thus we have no trouble in inferring from "All mome raths are partickeny" and "George is a mome rath," that "George is partickeny."

To explain the structural sensitivity of cognition, proponents of the similarity view might (as indeed we will) offer the mechanism of analogy. There is abundant evidence that analogy is structurally sensitive (Clement & Gentner, 1991; Gentner, 1989; Gentner & Clement, 1988; Gentner, Rattermann, & Forbus, 1993; Gentner & Toupin, 1986). However, opponents of similarity would challenge this move. First, analogy is not entirely content-independent, for it is dependent upon similar relations[3]. Second, even if we were to grant structure-sensitivity to analogy, this would still leave the bulk of similarity phenomena undefended. Finally, analogical processes are assumed to be instance-based. This synthetic character of analogy — that it is structure-sensitive and yet instance-based — has been considered highly problematic. (see, e.g., Smith et al., 1992).

Given these difficulties in assigning a role

3) On most accounts, an analogical pair must have common relations (Gentner, 1983, 1989). Thus "Northwestern lost the game." might be analogous to "The Gauls were defeated in battle" (because the relations are partly identical in semantic content), but a purely structural "vacuous match" such as "Northwestern lost the game" and "Fred loves chocolate." would not count as an analogy.

to similarity in cognitive processes that involve abstract rule-following, fans of similarity might try to take refuge in cognitive arenas that seem to rely on perceptual information, such as categorization. However, many researchers have produced evidence that people sometimes overrule similarity in making category judgments, classifying an instance as a member of category A rather than B even when they judge it to be more similar to B than A (Carey, 1985; Gelman & Markman, 1986, 1987; Keil, 1989a; Rips, 1987, 1989, 1991). So it appears that categorization goes beyond perceptual similarity information. Indeed, it has been argued that categorization is essentially theory-based, and arises from an abstract capacity not dependent on similarity. One might try to save a role for similarity in the earliest stages of development. Perhaps children's categories are more influenced by similarity when knowledge is lacking. However, Keil (1989a, 1989b), among others, has argued that a closer look at children's thinking "almost invariably reveals the presence of theoretical constraints" in their concepts and category judgments (1989b, p. 45).

In short, similarity is frequently depicted in the psychological literature as too context-dependent and too narrowly perceptual (or if not too perceptual, then too unconstrained) to account for abstract, rule-governed capacities such as reasoning and categorization. We claim, on the contrary, that a finer-grained analysis of the developing notion of similarity and a reassessment of the evidence reveals that similarity processes are central in the development of cognition. In the next section we articulate our theoretical framework and argue that similarity can be sufficiently constrained and sophisticated to play a role in these abstract capabilities, and that the very process of comparison is important in their development.

Similarity as Structural Alignment and Mapping

We propose that comparison takes place via a structure-mapping process of alignment of conceptual representations. According to this view, the commonalities and differences between two situations are found by determining the maximal structurally consistent alignment between the representations of the two situations (Falkenhainer, Forbus, & Gentner, 1989; Gentner, 1983, 1989; Gentner & Markman, 1997; Goldstone, 1994; Goldstone & Medin, 1994; Markman & Gentner, 1990, 1993, 1996; Medin, Goldstone, & Gentner, 1993). A *structurally consistent* alignment is one that obeys *one-to-one mapping* (i.e., an element in one representation corresponds to at most one element in the other representation) and *parallel connectivity* (i.e., if elements correspond across the two representations, then the elements that are linked to them must correspond as well). When more than one structurally consistent match exists between two representations, contextual relevance and the relative systematicity of the competing interpretations are used. All else being equal, the richest and deepest relational match is preferred (the *systematicity* principle). Arriving at a maximally deep structural alignment might seem to require an implausibly discerning process, or even advance knowledge of the point of the comparison. Such a mechanism would be unlikely as a developmental learning process. But in fact, structural alignment can be realized with a process that begins blind and local. The Structure-mapping Engine (SME) utilizes a local-to-global alignment process (Falkenhainer, Forbus, & Gentner, 1989; Forbus, Gentner & Law, 1995): it progresses from a rather blind initial stage of local, mutually inconsistent matches to having one or a few deep, structurally consistent alignments.

SME carries out its mapping in three stages. In the first stage, SME proposes matches between all identical predicates at any level (attribute, function, relation, higher-order relation, etc.) in the two representations. At this stage, there are typically many mutually inconsistent ($1 \longrightarrow n$) matches. In the second phase these local matches are coalesced into structurally consistent connected clusters (called *kernels*). Finally, in the third stage these kernels are merged into one or a few maximal structurally consistent interpretations (i.e., mappings displaying *one-to-one correspondences* and *parallel connectivity*)[4]. SME then produces a structural evaluation of the interpretation(s), using a kind of cascade-like algorithm in which evidence is passed down from predicates to their arguments. This method is used because it favors deep systems over shallow systems, even if they have equal numbers of matches (Forbus & Gentner, 1989). Finally, predicates connected to the common structure in the base, but not initially present in the target, are proposed as *candidate inferences* in the target. This means that structural completion can lead to spontaneous unplanned inferences. Thus, the process begins with local matches, but the final interpretation of a comparison is a global match that preserves large-scale structures.

This process model has some important implications for the process of comparison in development. First, because matches at all levels enter into the maximal alignment, the easiest and most inevitably noticed similarity comparisons are those of rich overall (literal) similarity. In this case the comparison process runs off easily, because the matching information is mutually supporting yielding one clear dominant interpretation. This suggests that children should perceive overall similarity matches before they perceive partial matches. Further, rich matches — such as two identical dachshunds — should be perceived earlier than sparse matches, such as two identical circles. A second implication is that when the local object similarities are inconsistent with the best relational interpretation — i.e., in cases of *cross-mappings* (Gentner & Toupin, 1986; Ross, 1989) — the outcome will depend on the relative strength of the object matches and the relational match. The greater the similarity of the cross-mapped objects, the greater the likelihood that the object similarity interpretation will win out, and the greater the depth and strength of the relational match, the greater the likelihood that the relational match will win out. (For adult evidence, see

4) Similar algorithms have been incorporated into other computational models of analogy, though none is identical to SME (Goldstone, 1994; Goldstone & Medin, 1994; Holyoak & Thagard, 1989; Keane & Brayshaw, 1988).

Markman & Gentner, 1993). In general, the winning alignment is a function of both object similarity and relational similarity.

An obvious but important third implication is that a relational alignment becomes more likely with increases in the degree of relational knowledge in the two domains. This leads to the developmental prediction of a relational shift with experience (Gentner, 1988; Gentner & Rattermann, 1991). Finally, SME's alignment process, taken as a model of human processing, suggests that the very act of carrying out a comparison promotes structural alignment and renders the common structure more salient (Markman & Gentner, 1993) This implies that when a child is induced to compare two things (for whatever reason, be it common labels, perceptual similarity, or similar roles in pretend play), the alignment process renders the common relational structure more salient. This is the conceptual bootstrapping function of comparison, to which we return later.

The Career of Similarity

Quine (1969, pp. 125–126) stated the case against similarity as well as anyone has: "The brute irrationality of our sense of similarity, its irrelevance to anything in logic and mathematics, offers little reason to expect that this sense is somehow in tune with the world..." (Quine, 1969, pp. 125–126). But he went on to propose a less negative view. He characterized the "career of the similarity notion" as "starting in its innate phase, developing over the years in the light of accumulated experience, passing then from the intuitive phase into theoretical similarity, and finally disappearing altogether..." (Quine, 1969, p. 138). This is the taking-off point for Gentner & Rattermann's (1991) "career of similarity" hypothesis, which proposes a shift in the kinds of similarity children can process with age/experience[5]. We suggest a recasting of Quine's dichotomy whereby "brute similarity" is similarity that is perceptual and object-based and "theoretical similarity" is similarity of relational structure (often of causal relations). For example, given sufficient knowledge about its behavior, a shark is alignable with a tiger: their causal commonalities mark them as members of the same relational category, "carnivores." Lacking such knowledge, the novice (or child) would be limited to "brute similarity" — to noting the likeness of shark to shark, or, less felicitously, of shark to tadpole.

Structural Alignment and the Career of Similarity

The assumption that perceiving similarity and analogy involves aligning two representations has developmental consequences, as noted above. It suggests that the easiest, most natural form of similarity to process is *literal similarity* (overall similarity), in which the object matches and the relational alignment are all consistently mapped. When there is conflict, as in a cross-mapping, then children should have more difficulty interpreting the comparison and should often accept the object match where adults would

5) Although inspired by Quine's discussion, our account differs in some ways from his proposal. In particular, unlike Quine, we claim that our sense of similarity has cognitive significance even in the last stages of development.

prefer the relational match. As with adults, the richer the object match, the more likely it is to prevail, and the larger and deeper the relational match, the more likely it is to prevail. Developmentally, the process of comparison is expected to be affected by the acquisition of domain knowledge. When domain theories are weak, as for very young children, the representations typically contain relatively sparse knowledge of relations and rich knowledge of objects. With increasing domain knowledge, children's relational representations become richer and deeper, opening up the possibility of perceiving and interpreting comparisons in terms of purely relational matches. Thus, there occurs *a relational shift*: children initially make object matches and overall similarity matches; with increasing knowledge, they become able to carry out purely relational matches.

Based on a review of the literature, Gentner & Rattermann (1991) amplified this account to propose the following account of the career of similarity. In the first stage, young infants respond to overall (literal) similarity and identity: when they see their mother bending over the crib, for example, they show that they relate this to prior instances of mother-over-crib and expect the same outcome. As another example, infants show memory for a mobile that they have seen before (by kicking in the same way to make it move) but only if there is a very close perceptual match with the original (Rovee-Collier & Fagan, 1981). The early stages appear governed by "global" or "holistic" similarity (Smith, 1989; see also Foard & Kemler-Nelson, 1984). Thus, as predicted, it appears that overall matches precede partial matches. The earliest partial matches are based on *object similarity*: direct resemblances between objects, such as the similarity between a round red ball and a round red apple. With increasing knowledge, children come to make *relational similarity* matches as well: matches based solely on commonalities in the relations that hold between objects or properties, such as the similarity between a ball *rolling on* a table and a toy car *rolling on* the floor. For example, when asked to interpret the metaphor *A tape recorder is like a camera*, 6-year-olds produced object-based interpretations such as *Both are black*, whereas 9-year-olds and adults focused chiefly on common relational structure: e.g., *Both can record something for later* (Gentner, 1988). Billow (1975) reported that metaphors based on object similarity could be correctly interpreted by children of about 5 or 6 years of age, but that relational metaphors were not correctly interpreted until around 10 to 13 years of age.

There is abundant evidence that the relational shift (or shifts, for the timing of the relational shift varies across domains) is at least partly driven by changes in knowledge (Brown, 1989; Gentner & Rattermann, 1991; Gentner & Toupin, 1986; Goswami, 1992; Vosniadou, 1989), although the alternative explanation of a global and/or maturational change in processing capacity has also been defended (see Halford, 1987, 1993). Evidence for the knowledge-change view comes in three varieties: (1) the relational shift occurs at different ages for different domains and tasks; (2) in particular, even very young children can show considerable analogical ability in highly familiar domains; and (3) children's analogical performance can be improved substantially by providing them with additional relational knowledge.

The Early Conservativeness Of Similarity

One implication of the "career of similarity" thesis is that children's earliest similarity matches should be highly conservative: that is, they should rely on extremely large overlap. There is considerable evidence for this claim (see Gentner & Rattermann, 1991, for a review). For example, Baillargeon has found that even young infants can use comparison to perform a rudimentary kind of inferential mapping. However, they can do this only under conditions of near identity (Baillargeon, 1991; Baillargeon, Spelke, & Wasserman, 1985). The study uses the habituation paradigm, in which infants' surprise at an event is taken as an indication that the event violates the infant's expectations. Normally, 4-month-old infants who have been habituated to a screen rotating back and forth through an 180: arc show no surprise when a solid box is placed behind the screen and in the path of its trajectory, and is (apparently) crushed into a tiny fraction of its former size. (Note that the apparent crushing of the box takes place behind the screen and out of the infant's line of sight.) However, if another box of the same size and shape is placed next to the to-be-crushed box, the babies show surprise at the crushing event, provided that this second box (which remains visible throughout the event) is identical or highly similar to the box behind the screen. For example, given a visible box that was red with white dots, the 4-month-olds could successfully make the mapping (and thus show surprise) if the "crushed" box behind the screen was red with green dots, but not if it was yellow with green dots or, worse, yellow with a clown face. This finding suggests that the babies are doing a kind of similarity-based mapping, using the box that is visible to infer (or remember) the size of the occluded box as it disappears behind the screen. What is striking is the conservativeness of the process. The babies appear to require a strong overall similarity match before they can make the match. Results like these bring home the magnitude of the human achievement in acquiring the kind of flexible, purely relational similarity capability that adults take for granted. Thus, the development of similarity proceeds from the perception of overall similarity between two situations to the ability to perceive partial similarity matches, and among these partial matches, object-matches precede relational matches.

Comparison can Promote Learning

There are at least four ways in which the process of comparison can further the acquisition of knowledge: (1) *highlighting and schema abstraction* — extracting common systems from representations, thereby promoting the disembedding of subtle and possibly important commonalities (including common relational systems); (2) *projection of candidate inferences* — inviting inferences from one item to the other; (3) *rerepresentation* — altering one or both representations so as to improve the match (and thereby, as an important side effect, promoting representational uniformity); and (4) *restructuring* — altering the domain structure of one domain in terms of the other (Gentner & Wolff, in press; Gentner, Brem, Ferguson, Wolff, Levidow, Markman, & Forbus, 1997). These processes enable the child to learn abstract commonalities and to make relational inferences. An important further conjecture is that comparison processes can be invited not only by experiential juxtaposition but also by what we might call "symbolic juxtaposition" through the learning of common linguistic labels.

To make these claims plausible, we now describe two lines of research in which young children showed substantial gain in relational insight after they were led to make comparisons, either through experiential juxtaposition or through common labels. Both studies followed the same logic. We first devised a relational mapping task sufficiently difficult that young children normally fail. Then we carried out interventions designed to create a change in children's knowledge and ask whether they are then able to see the relational mapping.

Progressive alignment and cross-dimensional matches. An appreciation of cross-dimensional similarity is a hallmark of abstract thinking. Kotovsky & Gentner (in press; Gentner, Rattermann, Markman, & Kotovsky, 1995) showed that experience with concrete similarity comparisons can improve children's ability to detect cross-dimensional similarity. Specifically, 4-year-olds' ability to perceive cross-dimensional matches (e.g., size symmetry and color symmetry) was markedly improved after experience with blocked trials of concrete similarity (blocks of size symmetry and blocks of color symmetry), as compared to control groups who received no training.

Kotovsky and Gentner's results suggest that re-representation is a natural extension of the comparison process. This process invites uniform representations of the objects and relations involved in the comparison so as to improve the match. The perception of commonalities in the comparison process is usually accompanied by the re-representation of the elements matched, or by the representation of their common structure at a higher level. Kotovsky and Gentner predicted that the comparison process would help children to detect the common higher-order structure of symmetry along different dimensions. Children's performance on cross-dimensional trials — such as *little/big/little* matching *light/dark/light* simply by blocking the within-dimension trials — such as little/big/little circles and little/big/little squares — before the harder cross-dimensional trials (even though children were given no feedback on their responses). We speculate that the within-dimension comparisons, being strong overall matches, are very easy for children to perceive. Each time a pair of these dimensionally embedded relational structures is aligned, their common structure is highlighted. Thus, repeated experience on within-dimension pairs permits the child to notice deep common structures, such as size symmetry or brightness symmetry. When these deep but dimensionally specific structures are juxtaposed in the cross-dimensional trials, the alignment process operates to promote re-representation of the comparison relations into a more domain-general format. We refer to this *process as progressive alignment*.

Symbolic juxtaposition through learning relational language. Rattermann & Gentner (1990; Gentner & Rattermann, 1991) designed a simple mapping task similar to DeLoache's (1985, 1989) model-room search task in order to investigate whether preschool children could align a simple perceptual relational structure. Children aged 3, 4 and 5 saw two triads of objects, the child's set and the experimenter's set, both arranged in monotonically increasing order according to size. The child watched as the experimenter hid a sticker under an object in the experimenter's triad; she was told that she could find her sticker by looking "in the same place" in her triad. The correct response was always based on relational similarity: that is, the child was meant to choose the object of the same relative size and relative position. (These two were always correlated.)

Rattermann and Gentner tested the predictions of the career of similarity hypothesis by varying the kind of alignment between the two triads. For example, as predicted, children were more accurate with literal similarity versions than with cross-mapped triads (in which the object matches were inconsistent with the best relational alignment). Further, the richer the objects (that is, the greater the local object similarities) the greater this advantage of literal similarity. Indeed, in the rich-object cross-mapped versions of the task, 3- and 4-year-old children performed at chance even though they were shown the correct response on every trial.

Having thus established a challenging relational task, Rattermann and Gentner then investigated whether the acquisition of relational language could help children perform this relational alignment. We again gave children the cross-mapping task, but this time we encouraged them to use the labels *Daddy*, *Mommy*, and *Baby* (or in other studies, *big*, *little*, *tiny*) for both their own triad and for the experimenter's. Their reasoning was that applying these labels to the three members of each triad would invite the child to highlight the higher-order relational pattern of *monotonic decrease* which forms the essential common system to align. (These family labels are often used spontaneously by preschool children to mark monotonic change (see Smith, 1989).)

The results of the labeling manipulation were striking. The 3-year-olds' performance in the cross-mapping task improved on both the sparse (89% relational responding) and rich (79% relational responding) stimuli. This is a substantial gain over their performance in Experiment 1 (54% and 32% correct, respectively). In fact, the 3-year-olds in this study performed at a level comparable to that of 5-year-olds in the non-labeled version. Further, these children were able to transfer this learning to new triads even with no further use of the labels by the experimenters. We suggest that the use of common relational labels invited attention to the common relation of monotonic change and made it possible for the children to carry out a relational alignment.

Kotovsky and Gentner also produced evidence for the power of relational labels to promote the detection of common relational structure across different dimensions. They taught 4-year-olds labels for the relations of monotonic change ("more-and-more") and symmetry ("even"). During the training task, children learned (with feedback) to classify the stimuli as to whether they were "more-and-more" or "even." After this training, the children who were successful in the labeling task scored well above chance in cross-dimensional trials (72% relational responding), as opposed to the chance performance (about 50%) with no such training. As in the Rattermann and Gentner studies, the use of relational labels had a strong effect in increasing children's attention to common relational structure.

The research summarized here suggests several conclusions. First, it supports the *career of similarity* thesis: children begin with highly concrete similarity matches and gradually become able to appreciate partial matches. Second, among partial matches we see a relational shift from early focus on object-based matches to a later ability to perceive purely relational commonalities. Third, this development is driven in large part by changes in domain knowledge. Fourth, we found support for the claims of the structure-mapping theory of the comparison process. The findings reviewed are consistent with our claim that children's early representations are conservative and context-specific, relying on massive overlap of perceptual features, and that they gradually develop relationally articulated representations, which enable them to appreciate partial similarity and analogy. We considered two ways of fostering relational insight: first, the progressive alignment of a series of cases so as to reveal common relational structure; and, second, the use of relational language to invite the perception of common relations. The first of these represents alignment through experiential juxtaposition; the second, alignment through symbolic juxtaposition.

We now turn to the role of similarity in cognitive development. We begin with analogical reasoning in children and then consider inductive inferences from categories. We then consider deductive reasoning, selected because it provides the best challenge to the similarity position. Finally, we consider word learning.

Analogical reasoning

Even more than adults, children often must reason in the absence of clear knowledge about the topic. We might therefore expect to see a fair amount of analogical reasoning among children. According to the career of similarity framework, children's analogies should initially be constrained by perceptual similarity between base and target, but should become increasingly independent of surface features as subjects acquire more knowledge of the target domain. Further, if our conjectures concerning the power of mapping processes to confer new knowledge are correct, then such analogies may play an important role in deepening and structuring domain knowledge.

We will focus on the biological domain. Beginning with Carey's (1985) work, this arena has provided a rich store of evidence. Carey asked children to make inductive inferences about properties. Children were told, for example, that a dog had a spleen and asked if bugs were likely to have a spleen. She found that before the age of ten, children tended to base their inductive attributions of biological properties on the similarity of the target object to humans. This pattern suggested that children might be using a well-understood species — their own species — to reason about less familiar species; that is, that they were drawing an analogy. The research of Inagaki, Hatano and their colleagues (Inagaki, 1989, 1990; Inagaki & Hatano, 1987, 1991; Inagaki & Sugiyama, 1988) has strengthened and clarified this interpretation.

This research demonstrated the importance of the person analogy in children's reasoning about mental and biological properties. They found evidence for two constraints on children's use of person analogies: a similarity constraint, which requires the target object to be more or less similar for the analogy to have application; and a "factual check or feasibility constraint," which demands that, after the analogy is attempted, the learner examine whether the analogical inference is consistent with the available knowledge about the target.

Both these constraints fit well with the structure-mapping account. High similarity tends to increase the likelihood of projecting an inference from an analogy because overall similarity (including perceptual similarity) renders the mapping easier. Further, since perceptual similarity is a fairly reliable indicator of phylogenetic proximity, perceptually similar species are likely to share structural features. This means that comparisons among high similarity pairs are more likely to yield valid inferences — that is, inferences that fit with the systematic causal structure of the target. In their 1987 study, Inagaki and Hatano found that the similarity of the target to humans had a significant effect on children's use of the person analogy. For all measures, the person analogy was used significantly more often for rabbits than for tulips. There is considerable evidence from other studies that young children's attribution of human characteristics to targets is proportional to their degree of similarity to people (Carey, 1985; Inagaki, 1989; Inagaki & Sugiyama, 1988).

Inagaki and Hatano's feasibility constraint, which requires that the inferences be consistent with what is known about the target, is also consistent with structure-mapping. In structure-mapping, this inferential consistency can come about either via a process of checking the validity of inferences after the mapping, or through the alignment process that occurs *before* the projection of inferences. In SME, the first step is normally to align the representations of base and target (except under specific circumstances: e.g., when nothing at all is known about the target). The projection of inferences is thus a kind of structural completion of the base structure in the target. According to the systematicity principle, this means that which inferences are drawn depends on the target as well as the base — specifically, on which system(s) of beliefs the target shares with the base (e.g., Clement & Gentner, 1991).

Inagaki & Hatano (1987, 1991) provided evidence for this kind of inferential selectivity by showing that children's use of the person analogy varies according to the type of situation. After demonstrating that children frequently use person analogies to generate inferences concerning situations where the target object and a person would react similarly (e.g. "too much eating" leading to death or sickness), Inagaki & Hatano (1987) tested children's inferences in cases where the predictions generated by a person analogy were inconsistent with children's knowledge of the target objects. For example, in the "left-behind" situation, children were told about a woman who left a caged rabbit/grasshopper or potted tulip in a store. They were then asked "What will the rabbit/grasshopper/tulip do?" As expected, children seldom used the person analogy when its predictions were in conflict with their specific beliefs about the objects. Inagaki & Hatano (1991) showed that this selectivity holds within an individual child. Children's justifications of their inferences also suggest selectivity in their use of the person analogy (e.g. "The grasshopper will be picked up by someone... It cannot walk, unlike a person;" see pp. 225–226).

A further prediction that follows from structure-mapping, as well as from the feasibility constraint, is that children's analogical inferences will be less accurate when they concern properties for which they lack precise knowledge. Consistent with this prediction, children's inferences concerning mental properties were less accurate than those for physical properties. When asked about mental states, children frequently used the person analogy to infer that the tulip/grasshopper/rabbit would feel happy or sad. Such inferences, though implausible from an adult point of view, were compatible with their knowledge of the target.

According to the analogical reasoning account, the person analogy has a special status in early analogical reasoning because people are a highly familiar domain for young children. An alternative account is that children reason from humans because humans are the core category members of their biological (or psycho-biological) domain. Inagaki (1990) provided strong evidence for the analogy account by providing children with a rich knowledge base about another species, namely goldfish. On the analogy account, they should be able to use this knowledge as a source of analogical reasoning about other animals, even though goldfish clearly do not qualify as the core animal species for us. Inagaki (1990) studied the influence of knowledge acquired through the experience of raising goldfish in 5-year-olds' inferences about biological properties. She contrasted the inferential abilities of two groups of children: the "experimental" or "goldfish-raising" subjects, and the "control" or "not-raising" subjects. Her study revealed three major findings. First, goldfish-raising children acquired a rich body of factual and procedural knowledge about goldfish: they answered factual questions (e.g., about the eating habits of goldfish) correctly far more often than not-raising children. Second, goldfish-raising children also acquired abundant conceptual knowledge about goldfish that enabled them to generate accurate inferences. They made more correct inferences about unobservable properties that humans and goldfish share, such as having blood, having a heart, or breathing. And when asked about the behavior of goldfish in novel situations, unfamiliar even for experimental subjects (e.g., about the goldfish not having been fed in a very long time), goldfish-raising children were able to make more reasonable predictions than not-raising children. Third, goldfish-raising children were also able to use their knowledge about goldfish as a source for making analogical inferences about unfamiliar aquatic animals such as frogs.

Interestingly, the goldfish-raising children tended to use the person analogy for a frog more often than the goldfish analogy. Inagaki argues that this is not surprising because knowledge about humans was still richer than that about goldfish for experimental subjects. Interestingly enough, these subjects used the person analogy for frog much more often than control subjects (15 explicit and 7 implicit person analogies produced by the experimental group, versus 8 and 4 produced by the control group). Inagaki suggests that children's knowledge of the underlying commonalities between goldfish and humans may help them overcome the surface-similarity constraint and apply the person analogy when control subjects would not normally use it. It is possible that goldfish-raising children were using goldfish as an implicit "bridging analogy" (see Clement, 1988), reasoning from humans to goldfish, and from goldfish to frogs. In any case, the important finding is that children's possession of more than one source for analogical reasoning changed significantly their patterns of inference.

In her examination of children's acquisition of knowledge through raising goldfish for an extended period of time, Inagaki found that analogy played an important formative role. Analogical reasoning is not restricted to special cases of inference concerning unfamiliar properties and situations, but rather, it can be an integral part of the process of knowledge acquisition. Inagaki argues that children seem to acquire conceptual knowledge about goldfish by transferring their knowledge about humans through the person analogy. She found that children often understood the behaviors and raising procedures of goldfish through analogy, and that they inferred unobservable properties of goldfish such as having blood or breathing by noticing commonalities with humans.

Analogical inference is not restricted to children. Inagaki & Sugiyama (1988) found that even adults often base their attributions of mental properties on perceptual similarity of the target to humans (more than 50% similarity-based responding). Consistent with the relational shift hypothesis, when queried about anatomical/physiological properties (about which they presumably know more than they do about animals' mental properties), 90% of the adults' attributions were category-based, while 70% of the preschoolers' attributions were similarity-based.

Simon & Keil (1995, p. 141) interpret these results to suggest that analogical reasoning is merely a fallback strategy, adopted when deeper knowledge is lacking, both for children and adults. They argue that, like adults, "preschoolers also seem to abandon the person analogy and draw inductions based on what appears to be a biological explanatory system when they are taught the functional role played by the taught property." We agree with their suggestion of a shift towards reasoning in terms of biological explanatory systems, but it is worth noting that such a shift could come about either through a shift from analogical mapping to category application or through a shift from mapping on the basis of perceptual similarity to mapping on the basis of common causal and functional relational structure.

The findings of Inagaki and her colleagues do not seem to support the idea that analogical reasoning is just a default strategy that children put aside in favor of theory-based induction as soon as they acquire the appropriate factual knowledge. They are at least as compatible with the description of a knowledge-driven shift from perceptual similarity to causal and relational similarity. Inagaki & Hatano (1987, 1991) have argued persuasively that children's use of person analogies, rather than being a sign of their general intellectual immaturity, as it is commonly assumed, is in fact a smart strategy that frequently leads to reasonable predictions and accurate attributions of properties. They have documented that children as young as 5-6 years of age often use constrained person analogies as a means "to generate an educated guess about less familiar, nonhuman objects" (1987, p. 1020). The primary conclusion to draw from those findings is that children's analogical reasoning is very adaptive, becoming increasingly constrained by causal and functional knowledge (Inagaki & Hatano, 1987, 1991) and knowledge about internal structure (Inagaki, 1990). Analogy plays a formative role in acquisition of knowledge when a well-structured domain provides the scaffolding for the acquisition of a new domain[6].

Analogical transfer in problem-solving tasks

There is a substantial body of developmental evidence that suggests that similarity-based transfer is initially conservative but can become increasingly flexible with training. While older children are able to detect the underlying structure shared by analogous problems, younger children tend to need surface commonalities to transfer solution strategies across different problems (e.g. Chen & Daehler, 1989; Gentner & Toupin, 1986), or explicit hints about the usefulness of prior problems (e.g. Crisafi & Brown, 1986). However, there is evidence that transfer based on abstract similarity can be induced during infancy for highly familiar relations such as containment (Kolstad & Baillargeon, 1991). Brown and her colleagues (Brown, 1989, 1990; Brown & Kane, 1988; Crisafi & Brown, 1986) have demonstrated that even young children can be quite successful in analogical transfer tasks if the do-

6) This is consistent with research suggesting that analogy can function as a mechanism of conceptual change both ontogenetically and in the history of science (Dunbar, 1994; Gentner, 1982; Gentner et al., 1996; Nersessian, 1992; Tweney, 1983; Wiser & Carey, 1983).

mains are familiar to them or if they are given some training in the relevant relations. They found that emphasizing task similarity and encouraging children to talk about the learned rules helped them to notice the appropriate problem similarity in more complex tasks. This is consistent with the career of similarity framework, which holds that the acquisition of representational uniformity in domain knowledge is facilitated by language learning and by the comparison process, which promote the regularization of domain representations.

Research on analogy suggests that the conservative character of children's transfer is tied to the specificity of their domain representations. For transfer to occur there must be some representational uniformity between the base and the target domain (Forbus, Gentner, & Law, 1995). When the transferable knowledge is highly contextual and specific, it is unlikely to match a new context except in very restricted circumstances. Thus, remindings and transfer should be highly conservative in young children for most domains, and for adults in domains in which they are novices.

Further, since this conservativeness stems from a lack of uniform and well-structured knowledge representations, acquiring systematic domain knowledge should increase the flexibility of transfer. Novick's research on the effects of expertise in mathematics (1988a, 1988b) provides some support for this view. She has shown that novices are heavily reliant on surface similarities in transfer, while experts are able to utilize structural commonalities. Even the experts were initially reminded of surface-similar problem, but they were able to reject them quickly.

This suggests that expertise may also be crucial in providing the subject with a stronger sense of soundness and relevance: that is, with a firmer capacity to discriminate the applicability of knowledge stored in memory. As Brown & Campione put it (1985, p. 185): "A major impediment to flexible learning is often not the lack of transfer ... but rather inappropriate transfer."

Two forces in the development of transfer

As discussed above, Gentner, Rattermann, Markman, & Kotovsky (1995) proposed two forces that drive the development of transfer from its initial conservativeness to its increasing abstractness and sensitivity to structure. These are language and the process of comparison (structural alignment). Language has the potential to highlight abstract commonalities that can support transfer, and it helps the subject to encode the base and target uniformly at the required level of generality. Gestalt researchers found that a simple labeling manipulation could help subjects to overcome the "functional fixedness" effect, while perceptual manipulations failed (Glucksberg & Danks, 1968; Glucksberg & Weisberg, 1966).

Common language may promote transfer. Clement, Mawby, & Gillis (1994) showed that the use of common relational labels can promote analogical retrieval. The developmental studies discussed above suggest that common relational labels can invite structural alignment and foster common relational structures (Gentner & Rattermann, 1991; Kotovsky &

Gentner, in press; Rattermann & Gentner, in preparation). All this evidence suggests that language has an important impact on transfer, making it less conservative and more adaptive.

The other major force in the development of transfer is the comparison process. As discussed above, the comparison process may serve to extract structural commonalities and may lead to stable abstractions that increase relational remindings[7]. Asking people to compare two analogs can prompt their re-representation at a more abstract level (Gentner, Rattermann, Markman, & Kotovsky, 1995; Gick & Holyoak, 1983; Kotovsky & Gentner, in press). There is also developmental evidence that comparison can facilitate later structural remindings. Chen & Daehler (1989) used a schema training condition in a set of transfer problems. The training provided to induce abstraction consisted mainly of similarity comparisons between the target problem and analog stories. This schema training manipulation proved to be very successful in facilitating transfer in 6-year-olds. In the Schema Training condition 88% of subjects successfully solved the target problem (versus 38% in the No Training condition). Thus comparison, viewed as a process of structural alignment, can be conceived of as an important mechanism of abstraction.

Deductive Reasoning

Rules versus similarity?

The dichotomy between rules and similarity has yielded two extreme positions in the research on reasoning. According to the natural-logic view (e.g. Rips, 1994), reasoning consists in the application of content-free syntactic inference rules: that is, in processes governed by formal principles that operate on the logical form of representations, irrespective of their content. On the other hand, according to instance models, reasoning relies heavily on specific experiences of rule applications and violations (e.g. Griggs, 1983). In addition, it has also been argued by norm theory (Kahneman & Miller, 1986) that people typically reason analogically, not only from past experience, but also by comparing the target situation to counterfactual alternatives constructed ad hoc (see also Smith & Osherson, 1989). There are also some hybrid views of reasoning. For instance, in mental model accounts, reasoning draws both on specific prior knowledge and on general knowledge of causal relations (Gentner & Stevens, 1983) or of the interpretation of logical terms such as quantifiers (Johnson-Laird, 1983).

Bringing the divide between rules and similarity to the subject's own mind, Smolensky (1988) has argued that reasoning involves one of two mechanisms: a conscious rule interpreter that processes knowledge algorithmically, and an intuitive processor that operates at the subconceptual level. A more specific proposal is Sloman's (1996) proposal of two independent but interacting systems of reasoning, one associative and similarity-based, and another symbolic and rule-based. Although we sympathize with Sloman's in-

7) A corollary of this view is that, since relational abstractions can arise not only from explanation and instruction, but also from the comparison between any two instances, unanticipated abstract structures may emerge occasionaly.

tegrative proposal, we think it is a mistake to restrict the role of similarity to associative and subsymbolic processes. The career-of-similarity framework suggests the possibility that different kinds of similarity may be involved in reasoning processes at different stages of development. Moreover, this framework suggests that the development of rule-based reasoning may be bootstrapped by carrying out comparisons between symbolically structured representations.

Deductive reasoning

Deductive inference rules are the best candidates for purely syntactic and content-independent rules, for their validity seems to be unaffected by the semantic content of the representations to which they apply. It has been commonly assumed that deductive processes, and abstract rule-following in general, are carried out regardless of content. Smith et al. (1992) argue that rule-following should be as accurate (if not more) with abstract as with concrete material, and with unfamiliar as with familiar material. In this section we survey evidence from adults and children to suggest that the developmental course of such abstract reasoning lies through the career of similarity.

There is evidence for effects of specific content in deductive reasoning. A large number of studies based on Wason's (1968) classic selection task have shown that while normal subjects typically fail in the application of conditional inference rules to abstract and unfamiliar material (in particular, they fail to apply Modus Tollens), their performance can be greatly improved if concrete and familiar material is used. In the selection task, subjects see four cards — e.g., "A," "C," "4," and "3" — and are told to turn over the necessary cards to test the following rule: "If a card has a vowel on one side, then it has an even number on the other side." Only a small number (about 10%) choose the correct two cards ("A" and "3"); the majority choose cards "A" and "4," suggesting that the participants, rather than following a rule of inference to test the conditional statement, were simply basing their choice on surface matches between the rule as stated and the cards (i.e., choosing the card that matched the antecedent (the vowel) and the card that matched the consequent (the even number).

However, it appears that performance is considerably better when the rule is stated in terms of a familiar domain in which the contingencies are accessible to the subjects. Wason & Shapiro (1971) used a thematic rule instead of an abstract conditional rule ("Every time I go to Manchester I travel by car") and a set of cards representing various destinations and modes of transport. They obtained 62% correct selection. Griggs & Cox (1982) found substantial improvement by using a familiar rule such as "If a person is drinking beer, then the person must be over 19." Johnson-Laird, Legrenzi and Legrenzi[8] (1972) found improvement (to 81% correct) using a familiar postal rule ("If a letter is sealed, then it has a 50 lire stamp on it") and a set of envelopes (sealed and unsealed, with a 50 lire or a 40 lire stamp). When the rule concerned an arbitrary relation between symbols, instead of a realistic relation between concrete objects, the subjects relapsed to the customary low level of performance. These studies strongly suggest that the source of facilitation was prior experience with the rule (including experience with counterexamples to the rule[9]).

The facilitation effects found in the Wason task are usually ascribed to "familiarity" with the rule and material used. Our framework allows us to be more specific and distinguish two different sources of facilitation: (a) *transparency* — the similarity between the prior knowledge representation and the representation of the conditional statement to be tested; and (b) *systematicity*, or the availability of higher-order structure that supports the application of the conditional inference. Systematicity can facilitate conditional reasoning because having access to higher order relations that correlate with the structure of the rule helps the reasoner to trace its implications[10] (Clement & Gentner, 1991; Gentner & Toupin, 1986). For example, Wason and Shapiro's thematic rule "Every time I go to Manchester, I travel by car" produces facilitation even for subjects who do not habitually travel to Manchester, because although the particular elements lack similarity with the constituents of the rule, reasoners have schemas linking modes of transport with destinations via meaningful causal or pragmatic higher-order relations, and these can be mapped onto the conditional scenario to provide constraint. In contrast, a rule such as "Every time I go into the kitchen I wear my brown shoes," even though it contains highly familiar elements, should produce little if any facilitation for the conditional rules. Subjects are likely to have mental representations of shoes of various colors and of different rooms in a house, but not lawful relations between them that they can map to the target rule. Thus transparency requires not only familiar elements but familiar relations among the elements.

If subjects have the appropriate higher order structure for testing a conditional rule, they should perform well in the selection task even with abstract and unfamiliar material. Indeed, the career of similarity hypothesis predicts that content effects should occur at a range of different levels of abstraction, since the level of abstraction achieved will vary with learner and with topic/domain. This

8) Smith et al. (1992) argue that the fact that Johnson-Laird et al.'s results do not always replicate casts doubt on the reliablity of content effects in this task. However, we think that the pattern of results obtained from replication studies is actually supportive of content effects. It appears that concrete content improves performance when the subjects are familiar with a causal or permissive rule in that context. This has been found in comparisons of subjects who did or did not know the postal rules: older and younger British subjects (Golding, 1981), British vs. American subjects (Griggs & Cox, 1982), and Hong Kong vs. American subjects (Cheng & Holyoak, 1985).

9) Jackson & Griggs (1990) and Rips (1994) argue that the very fact that dramatic changes can be obtained by subtle changes in problem presentation casts doubts on the reliability of the selection paradigm. These authors advise extreme caution in generalizing the pattern of results obtained with this paradigm to the whole domain of reasoning. We agree that it would be a mistake to hastily overstate the importance of content effects for all rules of inference. There is evidence for high level of performance with abstract material for rules concerning conjunction and negation (e.g. Braine, Reiser, & Rumain, 1984). But even if the content effects that the selection paradigm seems to demonstrate were specific to conditional rules of inference, this would still constitute an important phenomenon of complex reasoning.

10) In a different set of reasoning problems, Johnson-Laird and Shapiro (cf. Wason & Johnson-Laird, 1972) found that realistic relations facilitate performance when they correlate with the logical structure of the problem, but they hinder the deduction process when such correlation does not obtain.

seems to be the case. Highly specific scenarios can produce facilitation, as discussed above, but so can abstract schemas. As Cheng & Holyoak (1985, 1989) have argued, the higher-order relation of *permissibility* can be abstractly represented in a schema that would include rules such as "If Action A is taken, then Precondition P must be satisfied." Cheng & Holyoak (1985) tested performance on a selection problem that described a permission situation abstractly, using the rule "If one is to take action 'A,' then one must first satisfy precondition 'P'." Subjects gave 61% correct answers in the abstract permission problem, in contrast with a 19% success rate in the Wason card problem for the same subjects. However, the facilitation effect of systematicity with abstract stimuli may not be as strong as the facilitation of systematicity plus transparency (e.g., 81% in Johnson-Laird et al., 1972).

Cheng & Holyoak (1985) have proposed that people do not typically reason using content-free syntactic inference rules or representations of specific experiences, but rather using *pragmatic reasoning schemas*: "generalized sets of rules defined in relation to classes of goals"(p.391) or "abstract knowledge structures induced from ordinary life experiences" (p. 395). We agree that this intermediate level of abstraction is very common in everyday reasoning. The concrete-to-abstract route to reasoning schemas that Cheng & Holyoak (1985, 1989) propose is also very congenial to the career of similarity. However, there are three important differences between our framework and their pragmatic approach.

First, Cheng and Holyoak contend that "the schematic structures that guide everyday reasoning are primarily the products of induction from recurring experience with classes of goal-related situations" (1985, p. 414), and that those schemas are to be identified with respect to classes of goals. According to our framework, however, a higher order relational schema that supports conditional reasoning is needed for success in the selection task. But pragmatic schemas are not the only source of facilitation.

Goal-oriented contexts are undoubtedly a rich source of meaningful schemas, but there are many higher-order relational schemas that are not necessarily goal-oriented (e.g. causality, perceptual higher-order relations, mathematical relatedness, etc.). Humans learn regularities in the world beyond those that influence goal-achievement. Moreover, some schemas may be learned in a variety of pragmatic contexts, serving different kinds of goals (e.g. schemas of evidential relations), which makes it unlikely that their structure is derived from any particular type of goal. A second difference is that Cheng & Holyoak do not ascribe any special role to language in the formation of those schemas. Their theory dictates that "if reasoning performance is found to vary across populations, the explanation will lie not in linguistic differences, but rather in cultural differences regarding pragmatically important goals and situations" (p. 414). We contend instead that language is an important force in the development of relational schemas. Extrapolating from the research presented above, Gentner has conjectured that the acquisition of relational language may be crucial to the development of analogy.

A third important difference is that we do not suggest that pragmatic reasoning schemas are the end-point of development. With experience, people can and do develop abstract schemas that are no longer embedded in pragmatic contexts, and that relay purely on structural similarity. Thus we are not arguing that conditional reasoning is done only by analogies to prior experience. For example, Rips & Conrad (1983) found that a one-quarter course in elementary logic substantially improved subjects' ability to evaluate propositional arguments, many of which contained conditionals. For subjects sufficiently trained in conditional logic, the implications of complex rules may be readily available. Thus, on our account, people can advance beyond close similarity comparisons; however, we argue that the normal *route* to abstract representations is through similarity.

As expected on this account, children are highly sensitive to content in reasoning tasks. Girotto, Light, & Colbourn (1988) gave children a simplified version of the selection task. Following Cheng & Holyoak's paradigm, they used obligation and permission rules accompanied with brief rationales, as well as arbitrary rules. All the rules were unfamiliar to the children, and they were introduced in a game situation with toy bees and an imaginary beehive. An obligation rule, for instance, was "If a bee buzzes, then it must stay outside," followed by the rationale that the queen bee wanted to avoid spreading the disease to baby bees. An arbitrary rule was, for example, "If a bee buzzes, then it is outside." Children were then asked which of the bees should be checked (i.e., those inside, those outside, those that buzz, those that don't). As expected, children performed better with meaningful rules than with arbitrary rules (70% vs. 11% correct in 9- and 10-year-olds (Girotto et al., 1988).

Implications for language learning

There is an obvious analogy between the issues raised for deductive reasoning and those raised for grammar. In both cases, there is a system of competence in adults that is so extraordinarily fluent, and so basic to our cognitive functioning, that it cries out to be part of our natural endowment. And indeed, it remains an open question whether some parts of logic — such as *modus ponens*, perhaps — are indeed innate, and likewise for grammar. Nonetheless, we suggest that a detailed look at content effects in the acquisition and even in adult usage of grammatical constructs may reveal some of the same initial conservatism that we see in deductive reasoning.

Word learning

The striking facility with which infants learn new words has convinced many researchers that humans must come to the task endowed with a special capacity for word-learning. Quine's *gavagai* exercise points out the fact that children clearly do not entertain all of the logically possible hypotheses as to what a new word might mean. This has suggested to many researchers that there must be innate (or at least very early) constraints that guide the child's acquisition of word meaning. For example, Markman's (1989) whole-object and taxonomic constraints and Waxman's (1990) noun-category linkage have often been interpreted as innate constraints on word meaning. Other proposals have been even more specific. For example, P. Bloom (1994) proposed an abstract notion of *individual* that precedes the specific individuals that infants learn, and further that subtypes of individuals can be linked with various kinds of syntactic entities: e.g., between noun phrases and individuals, between count nouns and kinds of individuals, and between mass nouns and kinds of substances. We will suggest, in contrast, that word learning may obey the same cognitive principles we have discussed in other domains. This suggests several lines of prediction.

Order of vocabulary acquisition. Applying the career of similarity framework to word acquisition leads to two predictions. First, we might expect an early highly conservative or holistic stage in word acquisition before object meanings are extracted. Second, we would expect words for objects to enter the child's vocabulary before words for relations[11]. A further extension of the learning view is that early vocabularies should especially tend to include nouns whose referents are highly individuable in the perceptual world (Gentner & Boroditsky, in press). In particular, words for animate beings should be among the first terms acquired, animate beings should be easy to pick out, because of their common motion and coherent internal structure. Thus, words like *Mommy*, *Rover*, *Auntie*, and *kitty* are expected to be among the frequent early names. A further prediction is that, among inanimate referents, highly coherent, well-structured objects should be easier to individuate and name than objects with less determinate structure (see Imai & Gentner, in press).

Evidence for the first prediction, of an early pre-referential stage, comes from research suggesting that children do not immediately grasp the notion of object reference. In the transition from babbling to words, there is often an early stage in which children use protowords that appear to be contextually embedded parts of routines rather than true referential symbols (Dore, 1986; Halliday, 1975; Nelson, 1988). These protowords are often used in a highly conservative and context-specific manner. For example, Gillis (1987) observed a child who, at about 2 years of age, maintained a small set of protowords for several months. One of these was the early form "brrrm-brrrm," which the child initially used only while pushing a certain toy car. Gradually the usage broadened to other situations in which the child was pushing other small wheeled objects until finally, many weeks later, he used it to refer to a car he was sitting in. Only at that point could one confidently assume that the term was used referentially.

There is also evidence for the second prediction, that words for objects should be acquired before words for relations[12]. Children at around 1 1/2 to 2 years commonly

11) A third prediction is that words for higher-order relations should be acquired later than words for first-order relations, but this prediction is difficult to test because differences in word frequency and syntactic complexity are difficult to equate between higher-order relational terms and other relational terms.

experience a vocabulary spurt, which consists chiefly of concrete nouns (both common and proper) and has been called the "nominal insight" (Macnamara, 1982). Thus, the child's first truly semantic achievement is to extract and name objects separately from their contexts. There is considerable evidence that concrete nouns (including both proper and common nouns) outnumber verbs and other relational terms by a large margin in English both in early production vocabularies (Gentner, 1982; Huttenlocher & Smiley, 1987; Macnamara, 1982; Nelson, 1973) and in comprehension vocabularies (Goldin-Meadow, Seligman, & Gelman, 1976).[13] Even stronger evidence for the generality of the noun advantage comes from studies by Schwartz, Camarata, & Leonard in which children are presented with novel words, either as nouns or as verbs, and then tested for production of these words. Even when stress, frequency, phonological makeup, and word order are equated, children are more likely to produce names for objects than names for actions (Camarata & Leonard, 1986; Camarata & Schwartz, 1985).

In order to safely conclude that the reasons for the early noun advantage are conceptual or semantic factors, it is necessary to use evidence from several languages to establish the generality of the early noun advantage and to rule out various explanations specific to English, such as SVO word order and the greater morphological complexity and variability of verbs as compared to nouns, both of which are presumably disadvantageous to verbs in acquisition. Gentner (1982) studied early vocabularies from six different languages varying in their word order and morphological makeup and found an advantage for object terms over relational terms in all of them, although the degree of noun dominance varied with input factors. Korean is a particularly interesting language for this purpose because it has input properties that should favor the early acquisition of verbs — notably verb-final word order and the "pro-drop" feature whereby nouns may be omitted, resulting in verb-only sentences. Au, Dapretto & Song (1994) have reported dramatic evidence in support of an early noun advantage. Their studies of early vocabularies in Korean revealed that although Korean infants heard almost four times as many verbs

12) It should be noted that there is another factor, which we have termed relational relativity, at work in the late acquisition of verbs. Verbs and other relational terms — even in the perceptual domain — are more variable cross-linguistically than are concrete nouns. In lexicalizing the perceptual world, "...the assignment of relational terms is more variable crosslinguistically than that of nominal terms...Predicates show a more variable mapping from concepts to words [than do object terms]...Thus, for verbs and other relational terms, children must discover how their language combines and lexicalizes the elements of the perceptual field." (Gentner, 1982, pp. 323-325).

13) Gopnik & Meltzoff (1986) appear to disagree with this claim, but the disagreement seems to be more apparent than real. They report the predicted pattern of more object words than relational words in their corpus of early language (Gopnik, 1980, 1981). However, they note that more tokens of each type occurred for the relational terms, a pattern that Gentner (1982) also noted. Thus, there seems to be agreement that object-reference types outnumber relational types in English. This is all the more noteworthy since Gopnik utilizes an unusually broad construal of the notion "relational term." Along with terms that are generally agreed to be relational, such as "off," "down," and "more," Gopnik's count includes many terms that are commonly classified as social-interactional terms or as indeterminates, such as "there," "hooray," "no," and "bye-bye." These were counted as relational when the context was judged to warrant a relational interpretation (A. Meltzoff, personal communication, January 1991).

in the sentence-final position (the favored position for word acquisition), they nonetheless acquired far more nouns than verbs. Choi & Gopnik (1995) also investigated early Korean vocabularies. They also found a substantial verb advantage in input, but found roughly equal numbers of nouns and verbs in children's early vocabularies. Although their data do not show the strong noun advantage found by Au et al., the fact that children learned equal numbers of nouns and verbs despite what appears to be a substantial input advantage for verbs is some evidence for the claim that object terms are easier to learn[14].

There is evidence to support the prediction of early learning of names for animate beings. In Nelson's (1973) study of the first 8-10 words acquired by eight English-speaking infants, names for animate beings made up an average of 62% of the nominals and 41% of the total vocabulary. In a study by Caselli, Bates, Casadio, Fenson, Fenson, Sanderl, & Weir (1995), checklists were used to assess the early vocabularies of 659 English-speaking and 195 Italian-speaking infants. Caselli *et al*. found that two of the first five words produced on average in English (*Daddy* and *Mommy*) and four of the first five in Italian (*Mamma*, *Papa*, *bau-bau* (sound of dogs), and *Nonna* (grandmother)) were for animate beings. For the six children of six different languages whose early vocabularies (ranging from 15-42 words) are given in full in Gentner's (1982; Table 5) corpus, names for animate beings — including both proper and common nouns — accounted for from 33% to 100% of the first nominals and from 19% to 50% of the total early vocabularies. Furthermore, as expected, the proportion of animates to total nouns diminished as vocabulary size increases.

Object-based meanings precede relational meanings. Another line of evidence consistent with the career of similarity framework is that nouns whose meanings are relational — such as *island* or *passenger* — tend to be acquired later than simple object-reference terms (e.g., Gentner & Rattermann, 1991; Nelson, Hampson, & Shaw, 1993). Further, children at first tend to interpret such relational nouns as if they were object-reference terms. For example, Keil (1989a) found that preschoolers interpreted *island* as "a warm place with sand and palm trees", and *uncle* as "a friendly man with a pipe". Only later did they come to see the relational meaning of an island as a body of land surrounded by water, regardless of its particular attributes, and an uncle as a person in a particular kinship relationship. Likewise, Hall (1993) found that preschool children who were taught new relational terms, such as *passenger*, tended to interpret them as object-reference terms[15]. Only if they already knew an object-level name for the item were they likely to interpret the word as a relational term.

A related result stems from the body of

14) However, Choi & Gopnik did not include proper nouns in their count. Since these are often among the most highly represented object words in early vocabularies, omitting them could result in a subsstantial underestimate. However, Choi (personal communnication, August 1996) estimates that the animate entities category was not highly frequent. See Gentner & Boroditsky (in press) for further comparisons.

15) Hall & Waxman (1993) describe this contrast as one of "situationally specific" vs. " enduring kinds."

research by Markman, Waxman, and their colleagues, that has explored how the use of common nouns as linguistic labels can influence children's categorization choices. For example, Markman & Hutchinson (1984) contrasted children's categorization patterns with and without linguistic labels. They gave 2- to 3-year-olds a triad sorting task: e.g., putting a police car where it belongs, either with another car (same category, and also highly similar) or with a policeman (thematically related). The children shifted from roughly chance sorting (59% categorical sorting) to predominantly categorical sorting (83%) when a novel object name was used. ("This is a dax. Put it with the other dax.") It is noteworthy that the children didn't have to know in advance what the word meant in order to show this shift. They apparently believed that words pick out categories of like (rather than thematically related) objects.

But what does "like kinds" mean to young children? Imai, Gentner, & Uchida (1994) found, consistent with the relational shift, a shape-to-taxonomic shift in children's word extensions. They used the basic word vs. no-word task of Markman and her colleagues, but included in the choice set both a shape-similar (and taxonomically different) item and a taxonomic (but differently shaped) item, along with the usual thematic choice. They found that younger children (3- and 4-year-olds) tended to choose the same-shape item in the word condition (e.g. a tennis ball, given an apple as standard). Older children (5-year-olds) were relatively more likely to choose the same-category alternative. Gentner & Imai (1995) showed that this early same-shape preference in word extension was not an artifact of giving children an artificially difficult separation between taxonomic similarity and perceptual similarity. Even when preschoolers were given an alternative that was both same-shape and same-category as the standard (e.g., a pear, given an apple as standard), they were equally likely to choose the alternative that shared only shape with the standard (e.g., a tennis ball). This strongly suggests that perceptual similarity (shape similarity in particular) was the main determinant of word extension for young children.

Perceptual similarity is not the only influence on category membership judgments and inferences. For example, Carey (1985) observed that children and adults judge a human to be more similar to a toy monkey than to a worm, and yet, when told that humans have spleens, they are more likely to infer that the worm has a spleen than that the toy monkey does. Rips (1987) found a similar dissociation between categorization and similarity in adults: a bird that is transformed to look like an insect is still judged by subjects to be a bird. In light of these dissociations, category-based induction has come to be seen by many researchers as essentially theory- and rule-based, rather than as similarity-based[16]. However, as we have argued throughout, similarity can be based on common relations or common perceptual attributes or both. Goldstone (1994) sug-

16) Osherson, Smith, Wilkie, Lopez, & Shafir (1990), however, have proposed a similarity-based model of argument strength (the "similarity-coverage model") for category-based induction. This model attempts to account for the apparent dissociations between similarity-based and category-based induction.

gests that subjects often take similarity questions as invoking perceptual similarity. He found that when similarity was probed using a question form that elicited conceptual rather than perceptual similarity judgments, similarity and categorization judgments were largely correlated. Expressed in its deepest terms, the problem is that similarity is not a unitary notion (Gentner, 1989; Medin, Goldstone & Gentner, 1993).

Category-based inference: interrelations between language and similarity

Word-learning is a major engine for the acquisition of new knowledge. A child who is told that a new exemplar is a cat, for example, can then immediately know about its properties and nature. A growing body of research, much of it by Gelman and her colleagues, has explored the ways in which the use of common nouns as linguistic labels can influence children's inferences (Gelman, 1989; Gelman & Coley, 1990; Gelman & Markman, 1986, 1987;Davidson & Gelman, 1990). These researchers have discovered a fascinating interplay between perceptual similarity and common linguistic labels in children's inductions. Gelman and Markman (1986) found that by age four children already use, to some extent, category membership to support inductions when given familiar labels (e.g., "bird"). In their study, children made inferences about an animal's properties (e.g., "eats meat", "hides food in the ground") on the basis of both its category label and its perceptual similarity with a standard item. When the animal was perceptually similar to standard and was given the same label, the children made category-based inferences on 88% of the items. When similarity was lacking but a common label was used, children gave 68% category answers. Thus, perceptual similarity was influential, but children were also influenced by the presence of common linguistic labels.

Davidson & Gelman (1990) showed larger similarity effects with novel categories. Unlike previous studies of category-based induction that used familiar objects with familiar labels, Davidson & Gelman used not only unfamiliar properties ("has four stomachs"), but also novel objects (e.g., a gnu-like animal) and novel labels (e.g., 'zav'). The child was taught a property of a standard animal, then asked whether the property would be present in another animal. In order to tease apart similarity and common label, they were shown four animals in a 2 × 2 design (Similar or Nonsimilar; Same or Different Label). In their first two studies, they found that 4- and 5-year-old children drew more inferences to pictures that were perceptually similar to the standard (about 75%) than to those that were perceptually dissimilar to the standard (about 45%). There was no effect of common labels, whether the labels were novel (Experiment 1) or familiar (Experiment 2). Only in their third study, in which the correlation between similarity and common label was improved by omitting one of the "conflict" pictures in each set, did common label have an effect, but only when supported by appearances (65% for same label vs. 47% for different label). When there was a contradiction between labels and appearances, children based their inferences on appearances. This research suggests that "children do not have a completely general assumption about the power that language has for conveying the deeper identity of novel objects" (Davidson & Gelman, 1990, p. 174). It also underscores the role of perceptual similarity as the early basis of inductive inferences.

Gelman & Markman (1986) and Davidson & Gelman (1990) have suggested that children notice that the members of a category have many observable features in common and they eventually extend this belief to unobservable properties as well. Their findings suggest that this extension is promoted by the acquisition of category labels[17]. This is consistent with the career-of-similarity framework. Gentner & Rattermann (1991) have argued that for the linguistic child, "a word can function as a promissory note, signaling subtle commonalities that the child does not yet perceive" (p. 260). However, Davidson & Gelman's data also suggest that the power of common labels in category-based induction is initially bootstrapped by perceptual similarity.

In light of their findings, Gelman & Markman (1986) note that at age four there is only "an unsophisticated, undifferentiated belief in the richness of categories" (p. 186) and that "there is much left for children to learn about the relationship between categories and induction" (p. 205). With experience and instruction, children learn to sort out which properties and relations are expected to be common to members of different types of categories. Moreover, the child must learn which kinds of relational commonalities are characteristic of different categories. As Gelman (1989) points out, artifact categories have different kinds of commonalities from animal categories (e.g., characteristic external relations (functions) vs. characteristic internal relations). The shift from surface similarity to similarity of relational structure in category-based induction requires, in our view, the acquisition of domain knowledge.

Discussion

We have argued for the career of similarity account of the development of cognition, and have speculated that this account may apply to some aspects of language learning as well. We suggest that a common progression is from overall, highly perceptual similarity to higher-level abstract similarity. We have also suggested that comparisons, explicit and implicit, underlie or influence many different cognitive processes. Thus, as similarity comparisons evolve from being initially perceptual and context-bound to become increasingly framed in terms of common higher-order structure, children are able to notice and reason about increasingly abstract situations.

The structural alignment and mapping process we propose is one that grades naturally from highly concrete and liter-

17) In their 1987 study, Gelman and Markman found that 3-year-olds are inclined to make inferences based on category membership even when labels are not provided. Even in the picture only condition, category-based responding was dominant. However, the categories used in this study (cat, rabbit, snake, bug, bird) were very familiar and their labels likely to be known by 3-year-olds. So this finding does not refute the possibility of a relationship between children's linguistic knowledge and their category inductions.

ally similar comparisons to purely abstract comparisons[18]. A role for structural similarity is implicitly granted in Fodor & Pylyshyn's account, for, as they put it, any theory in which mental processes are structure-sensitive must perforce acknowledge the importance of representations with "similar structure," and "will predict that similarly structured representations will generally play similar roles in thought" (p. 48)). Our point is not that structural similarity can replace abstract rules altogether. Rather, we suggest, first, that it is an open question how much of expert cognition is rule-governed vs. analogy-governed; and, second, that structural similarity provides the necessary bridge from experience to rules. Comparison is fundamental to the development of cognition.

The career of similarity framework predicts a developmental trend from overall similarity to relational similarity and abstract mappings. This progression should occur at different rates in different domains, depending in part on experience. Learners advance in this continuum piecemeal, that is, in a domain-specific fashion. This framework also emphasizes the possibility of cognitive pluralism, for in the career of similarity the later phases do not supersede the earlier ones. As Quine puts it (1969, p. 167), we "retain different similarity standards ... for use in different contexts." According to our framework, rule-governed processes are based on abstract structural similarity, but they may coexist in adult cognition with processes governed by lower-level similarity.

Our assessment of the developmental evidence suggests that the features characteristic of abstract cognition that Fodor & Pylyshyn (1988) emphasize (productivity, systematicity/compositionality, and inferential coherence) are not a given, but the product of learning. Young children's linguistic and perceptual representations are highly context-bound[19], but they become increasingly systematic and structured with development. The career of similarity framework is an attempt to account for this trend of increasing abstraction. As for the fourth feature of cognition emphasized by the syntactic approach (Rips, 1994; Smith et al., 1992), its content-independence, our review of the evidence suggests that such purely abstract reasoning is the result of considerable experience. Adult novices often — perhaps typically — show strong content effects in both reasoning and transfer that seem to be directly linked to similarity-based processes.

Similarity is often treated rather slightingly in current theories of cognitive development. We suggest that similarity — even mundane within-dimension similarity — can act as a positive force in learning and development. We have argued that the simple process of carrying out similarity and analogy comparisons may play a fundamental role

18) Indeed, there is a natural link between SME's algorithm for analogy and the application algorithms for matching instances to structured category descriptions (by using variables instead of constants in the category representation).

19) The syntagmatic categories of children's early language are event-specific (e.g. "hitter" and "thing hit"), not event-general roles such as "agent" and "patient" (Tomasello, 1995). There is also evidence that infants' perception of causal events does not involve the representation of agent-independent causal structure, but it is rather crucially dependent on the type of agent involved (Cohen & Oakes, 1993).

in the development of structural representations.

Although we have focused on the comparison process, we want to state clearly that comparison is only one of many learning mechanisms involved in the route to abstract cognition. Explanation-based learning, routinization, and many other learning processes must be invoked as well. Another major force in development is enculturation. Among other things, cultural learning, including language learning, invites comparisons that lead the learner to see subtle or abstract commonalities that would otherwise pass unnoticed. We propose that similarity, viewed as *a process of comparison*, is a learning mechanism that links cultural learning — in particular language learning — with experiential learning.

The role of language in comparison. Throughout this paper we have emphasized the role of language in inviting symbolic juxtapositions. By giving two things the same name, we invite children to compare them whether or not they occur in experiential juxtaposition. We conjecture that learning words for relations is crucial in the development of analogy. Such learning promotes representational uniformity, in that it increases the likelihood that the learner will encode relations in the same way across different situations. Further, we suspect that the gains in representational uniformity are greater for relational concepts than for object concepts for the reasons alluded to above. Children's concepts of concrete objects and animate beings achieve representational uniformity by virtue of their perceptual and conceptual coherence (Gentner, 1981, 1982). This may be one reason that object commonalities seem to dominate over relational commonalities (even for adults) in analogical reminding tasks (Gick & Holyoak, 1983; Gentner, Rattermann, & Forbus, 1993; Keane, 1988). Thus we speculate that learning relational terms, by promoting representational uniformity, can increase the likelihood of structural transfer. This is because it should increase the likelihood that the learner will retrieve a situation or event given another with the same relational structure, *even assuming "dumb" retrieval processes* (as postulated by Forbus, Gentner, & Law, 1995).

Thus we propose, following Vygotsky (1962), that the acquisition of language — of a symbol system — is a major watershed in cognitive development. Not only does language provide the child with relational reference terms, but it provides a model of a fully compositional system. Vygotsky argued that with the advent of language children augment their repertoire of pre-linguistic cognitive capabilities — reactive attention, associative learning and sensorimotor intelligence — with post-linguistic capabilities of focused attention, deliberate memory and symbolic thought (see also Dennett, 1993). We would augment this proposal by noting that symbolic representations permit structural comparison processes[20]. Once language is present, the child (we hypothe-

20) We do not suggest that the child is a passive recipient of the symbolic system embodied in the language she learns. Pre-linguistic children can interpret referential gestures, and as Goldin-Meadow (1993) and her colleagues have shown, a symbolic system may be co-constructed by child and adult.

size) continues to use this associative system, along with a symbolic system with structural representations and structured comparison processes. There is recent intriguing evidence of new cognitive capabilities at around the time that language emerges. Mandler & McDonough (1993) find that 14-month-olds and probably 11-month-olds, but not 7-9-month-olds, will imitate actions across basic level categories. Xu & Carey (1995) have found evidence that 12-month-olds, but not 10-month-olds, individuate objects on the basis of object kind. Further, this ability may be correlated with the possession of object words. (Whether this ability relates to knowing names for the specific objects used in the study remains an open question.)

The role of comparison in language learning. How far can such structural comparisons go in accounting for the learning of language? We have argued that this framework can usefully be applied to word learning. It may turn out to be necessary to invoke innate word categories, but we think it is worth pursuing the possibility that a combination of cultural support and known learning mechanisms, including structural alignment and comparison, may go a long way towards accounting for the acquisition of word meaning.

But even if word meaning proves amenable to the new empiricist effort, that still leaves the serious challenge of accounting for the acquisition of grammar. There are promising efforts underway to apply structural analogy mechanisms to the way in which children align sentence structure with experiential structure (e.g., Fisher, 1996). It may turn out that, as we have suggested for deductive reasoning, at least some aspects of our phenomenal elegance and power of our adult symbolic and grammatical capacities are brought about by gradual structural abstraction.

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