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Structural Constraints on Cognitive Development: Introduction to a Special Issue of *Cognitive Science*

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Jean Mandler set the stage for the preparation of this isssue when she invited me to organize a symposium on constraints on cognitive development for the 1986 meeting of the Psychonomic Society. In responding to Jim Greeno's suggestion that we prepare manuscripts based on those talks, we tended to focus on a particular question: How is it that our young attend to inputs that will support the development of concepts they share with their elders? Keil's concluding article in this volume returns to the broader issues raised by the symposium discussion and provides a framework for the many ways the notion of constraint is used in cognitive science. His analysis of the concept of a developmental constraint also organizes his comments on the articles in this issue.

The question of how the young focus on those aspects or descriptions of experience that lead them to induce the concepts they share with elders is not new. The roots of the modern discussion are in the writings of the British Empiricists and the responses to them, especially Kant's. Two longstanding problems that are central to the papers in this volume—the indeterminancy or inadequacy of experience and the pluri-potentiality of experience—are

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The text is based in part on my introductory comments to a symposium entitled, *Structural Constraints on Cognitive Development,* at the meeting of the Psychonomic Society, St. Louis, November, 1986. I thank Jean Mandler for suggesting that I organize the symposium and Jim Greeno, who had the idea that the symposium serve as the germ for this issue of *Cognitive Science.* Together they have provided important opportunities to share the fruits of several working groups, including one that met for a week-long set of tutorials at the University of Pennsylvania, June 1984; and another that met weekly during 1984–1985 at the Center for Advanced Study in the Behavorial Sciences, Palo Alto, CA.

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central to current discussions of the acquisition of syntax (Landau & Gleitman 1985; Wexler & Culicover, 1980), visual perception (Marr, 1982; Ullman, 1980), the nature of concepts (Armstrong, Gleitman, & Gleitman, 1983; Medin & Wattenmaker, 1987), and the learning of word meaning (Macnamara, 1982; Quine, 1960).

Experience is indeterminant or inadequate for the inductions that children draw from it in that, even under quite optimistic assumptions about the nature and extent of the experiences relevant to a given induction, the experience is not, in and of itself, sufficient to justify, let alone compel, the induction universally drawn from it in the course of development. For example, there is nothing in the environment that support a child's conclusion that the integers never end. Experience is pluri-potential in that the same experience is potentially relevant to extremely diverse inductions. The experiences we provide do not guarantee that the learner will focus on the interpretation that accords with our didactic intent. Quine's well known example (1960) of the language learner who has to determine what her 'teacher' means when she points to a scene like that in Figure 1 and says "gavagai" underscores this point. Does the teacher want the learner to associate the novel term with the rabbit's ears, fingers, fur, or body? Does 'gavagai' refer to the ground on which the rabbit is standing; the instrument it is holding; the pattern on its front, and so on? Which of the infinite number of possibilities is the naive learner to impose on this setting; and how does the child know which one?

The 'gavagai' puzzle reminds us that the relationship between a label and the context in which it is uttered is ambiguous *because environments are ambiguous and underdetermined*. Working within the information processing tradition, Newport offers one kind of solution to the problem of environmental indeterminancy. She develops the intriguing idea that limits on the information processing capacities of the young assist their learning. These limits cause the young to bypass much of the surface data and instead take in bits and pieces. Since language relevant data are often characterized as features, the focus on bits and pieces is especially well suited to the task of inducing the morphemic and syntactic rules of the input language. The results should be that the young child is actually favored over the adult when learning to master the novel structure of an input language. Newport's data from comparisons of adult and child learners provide evidence for this prediction.

Another way to characterize Newport's position is to say young children respond to the right language data because of a general limit on their attentional capacities. Although a bit-and-piece processing rule may work well for language, it may not in other domains. Indeed, Newport joins other theorists in the information processing tradition (e.g., Siegler, 1983; Simon, 1972) when she suggests that limits on the processor explain why the young fail many cognitive tasks that older children and adults pass.

Figure 1. Mary McManus' interpretation of the White Rabbit in Lewis Carroll's *Alice in Wonderland*.

The remaining papers in this issue offer a different kind of account of how young learners manage to focus on the right kind of data for learning about numbers, causes, objects, the animate-inanimate distinction, tools, or artifacts. A common theme in these papers is that it is necessary to grant infants and/or young children domain-specific organizing structures that direct attention to the data that bear on the concepts and facts relevant to a particular cognitive domain. The thesis is that the mind brings domain-specific organizing principles to bear on the assimilation and structuring of facts and concepts, that learners can narrow the range of possible interpretations of the environment because they have implicit assumptions that guide their search for relevant data.

Spelke's research supports her position that infants have implicit structuring assumptions about the world they will enter, a key one being that there will be *things* in it. The 'thingness' assumption guides attention to data that are relevant to identifying things, information about whether bounded entities or parts move together along common paths. When an infant, using such information, identifies a thing, he or she is then able to go on to learn about its sensory characteristics. Thus, for Spelke, the concept of a thing is not an induction from an associatively organized store of first-order sensory experiences (gleanings from William James' "blooming, buzzing confusion"); it is an a priori organizing concept that structures the assimilation of such sensory inputs.

Ellen Markman argues that the child makes assumptions about how things and the constituents of things are to be labeled. The child assumes that a novel label applies to a novel object as a whole, as opposed to a part of it or its color. Once the child has a name for the object, he or she then assumes that further novel terms apply to other aspects of that object, for example, the material it is made from. Markman's work provides us with a part of the answer to the puzzle Quine posed with his gavagai example.

I turn to why young children are able to treat the same objects in the environment as props for counting, causal reasoning, or labeling without getting these functions all mixed together. My answer is that they interpret the environment with reference to different skeletal sets of domain-specific principles. This kind of account is related to discussions about the problems of defining conceptual coherence.

People studying the nature of concept formation and transfer in adults have had considerable trouble defining similarity solely on the basis of the low-order sensory characteristics of an object, its visual appearance, sound, or feel. This has led Medin and his collaborators to ask what contributes to conceptual coherence (Medin & Wattenmaker, 1987; Murphy & Medin, 1985). A similar problem confronts those who ask what generates rapid transfer and/or acquisition during development or in adulthood. Efforts to obtain rapid transfer based on a sensory or perceptual similarity have met with limited success (see Brown & Kane, 1988). One current solution to these problems is to appeal to the idea of theories (e.g., Carey, 1985). Investigators note that a particular concept is often related to a class of concepts, which compose a more or less coherent set of principles or assumptions. Rather than trying to ask what are the necessary and sufficient criteria for the concept *dog,* one asks what principles organize our knowledge of dog-like things. If we say they are like the principles of biology, then we might conclude that whatever a dog is, it is certainly something that breathes, eats, sleeps, reproduces, has the capacity for self-generated motion, can perceive, and so forth. Furthermore, we can say that other objects which share these attributes are in the same general category, and we can go on to say that objects which reproduce in a similar fashion are more alike than are those that reproduce in a different way. Note how the idea that core principles of biology that organize our concept of dog carries with it the implication that this concept is related to other concepts. Furthermore, the core principles provide a rule of similarity that is not based on the distances between objects in a low-order sensory space.

Ann Brown, Frank Keil, and I develop variants of the argument that conceptual coherence and/or the transfer of causal concepts are promoted by domain-specific principles about causality. I argue that two principles of mechanism guide learning inferences about the animate-inanimate distinction. They do so by focusing attention on perceptual data that are relevant to the distinction, including sensory properties that carry information about material kind, patterns of movement, and so on. Ann Brown shows that learning about tool use and related causal relations is rapid and transfers with ease when young children can focus on the characteristics of an object that make it an instrument for pushing or pulling. In contrast, learning and transfer are not easy if attention is focused on the color or decorative aspects of the same objects. Keil appeals to the notion of causal origin to account for several kinds of early conceptual coherence. Spelke marshals evidence for granting infants central mechanisms designed to abstract coherent information about an object as a whole as well as how objects move and interact in space.

I end my introductory comments with three caveats concerning possible misconceptions about the notion of constraints (or constraining principles) as enabling factors in development. In her critique of constraint accounts of word learning, Nelson (1988) asserts that very young children would never make an error if there were constraining factors guiding acquisition and implies that the position is necessarily a nonlearning theory and therefore incompatible with the fact that our young learn about everything they know. But the constraint position is neither a nonlearning theory nor commited to error-free performance from the beginning. Indeed, none of the following authors who develop a constraint position go on to claim that *all* knowledge is innate, as if all an infant needs to do is await the correct stimulus trigger to show off their full blown concepts. None advance the idea that there is no learning or development. Quite the contrary, all are attempting to develop *learning* theories and all assume that there *is* learning. What some reject is the assumption that domain-general learning theories are adequate. The search is for a learning theory that deals with the problems addressed above. Those of use who postulate a priori structural constraints do so because we believe that these can help a child make better *guesses* about the novel. But guesses they remain and therefore they cannot be correct at all times. Logically then, performance and acquisition have to be variable. Variability per se is *not* a sufficient criterion for distinguishing between learning theories that either do or do not assume constraints on induction (cf. Gelman & Greeno, 1989; Gelman & Meck, 1986).

Second, some of us argue that principles, or a priori representational structures, or theories must guide and structure early development. But this does not mean that we assume that these are formulated in language or other mature symbolic systems, or that they exert their effects by way of such systems. No one imagines monologues in the infant mind, one which refer to principles articulated in some language-like form for guidance on how to interpret the world. Instead we have in mind the kind of commitments to the structure of experience that are implicit in the processes that assimilate and structure data. The argument is analogous to Marr's idea that there are principles that are implicit in the processes and mechanisms that process visual data. Similarly, Gelman and Greeno (1989) assume an implicit set of preverbal counting principles contribute to the plan system that is part of the information processing system that generates and judges acceptable instances of counting. Gelman and Greeno's proposal that learning to re-represent the counting principles with language is enabled by the presence of the early skeletal set of nonlinguistic counting principles resembles Karmiloff-Smith's (1979; in press). She argues that, during early cognitive development, there are mechanisms that are not stated in language that nonetheless make implicit commitments to the structures of experiences and that support acquisition.

Finally, part of Keil's paper discusses the other papers in this issue. The logistics of preparing this issue required Keil to work from penultimate versions of the papers in preparing his commentary. Some of the final versions involved substantial changes of material that Keil comments on. He was able to make some adjustments in his text with the final versions in hand, but major reformulations of the paper would have delayed completion of the project unduly. I assume that some degree of dysynchrony would continue no matter how many rounds of scrutiny the papers when through. Each of us has different views of each others' positions and how to respond to comments about our own work, a fact that underscores one of Keil's main points.

The papers that follow do not present a united front on the notion of constraint. There *are* many ways to think about the role of constraints in cognitive development in particular, and cognitive science in general.

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