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CHAPTER TWENTY-FIVE

Domain. specificity in cognitive development: universals and nonuniversals

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An account of domain specific theories *of* cognitive development is presented. One theme is that there is an ongoing change about the meaning of key theoretical tams, including *learning*. The account of learning highlights the role of structure-mapping and other mental lemming tools, as opposed to the laws of association. Another theme is that there are core and noncom domains, ones that do and ones that do not benefit from innate skeletal structures. Much of the discussion about domains is organized around a series *of* questions, including: What is a domain; What is and Is not innate; What constitutes lemming in a domain; How many domains are there; How can knowledge be innate and yet variably applied; How can a domain be both innate and learned; and How can we distinguish between universal and non-universal domains?

Sort ici expoa6es lea theories du developpement cognitif invoquant 1'existence de domaines specifiques. Un des themes abordfs concerne le changement en cours daps In signification de termes cles sur Ie plan theorique, y compris celui *d'apprentissage*. La section relative it l'apprentissage met en evidence Ie rble do Ia cartographic des structures et d'autres outils d'apprentissage mental, en les contrastant par rapport aux lois d'association. Un autre theme a.trait it ('existence de domaines centraux et d'autres non centraux, scion qu'ils s'appulent oat non sur des structures fondamentalea inn6es. L'essentiel de Is discussion relative aux donaines s'articule autour d'une sane de questions: par exemple, quest-ce qu'un domain; qu'est-ce qui est inne et qu'est-ce qui ne l'est pas; qu'est-ce qu'apprendre dens un domain; con bien y a-t-il de domaines; comment In connaissance peut-elle Nre innae tout en etant appliqu6c de maniere variable; comment un domain pout-ii etre it Is fois inn6 et appris; et comment distingusr entre des domains universels et d'autrcs non universals?

INTRODUCTION

The focus of this chapter is on domain-specific accounts of cognitive development. A question and answer format is used to cover key issues about this class of theories, including what counts as a domain, the nature of domains, and whether domains are innate. Gelman and Williams' (1997) distinction between *core* and *noncore* domains is a leitmotif that appears throughout the discussion. We assume that it is only *core* domains that benefit from innate contributions to their epigenesis, both core and noncore domains are learned. The presence of skeletal structures for core concepts, e.g. objects, and natural number, facilitates early learning about these domains. To master a noncore domain, e.g. chess, literary criticism, or sushi making, one has to acquire both the structure and body of knowledge in that domain.

KEY QUESTIONS ABOUT A DOMAIN-SPECIFIC THEORY OF COGNITIVE DEVELOPMENT

What is a domain?

I define a domain of knowledge in much the same way that formalists do, by appealing to the notion of a set of interrelated principles. A given set of principles, the rules of their application, and the entities to which they apply together constitute a domain. Different structures are defined by different sets of principles. Therefore, we can say that a body of knowledge constitutes a domain of knowledge if we can show that a set of interrelated principles organizes its rules of operation and entities. Sets of principles carve the psychological world at its joints, producing distinctions that guide and organize our differential reasoning about entities in one domain versus another. In this way, available domain-specific structures encourage attention to inputs that have a privileged status because they have the potential to nurture learning about that domain; they help learners find inputs that are relevant for knowledge acquisition and problem solving within that domain.

Counting is a part of a number-specific core domain, because the representatives of numerosity (what I call numerons), generated by counting are operated on by mechanisms informed by, or obedient to arithmetic principles. For counting to provide the input for arithmetic reasoning, the principles governing counting must complement the principles governing arithmetic reasoning. For example, the counting principles must be such that sets assigned the same cardinal numeron are numerically equal and sets assigned different cardinal numerons are either greater than or less than each other in value. However, their engagement does not require attention to the weight or kind of material of the items being counted. In contrast, causal principles encourage attention to variables that bear on how to move the items around, variables like the weight and material of the objects. The analysis of the cause of an object's movements is based on domain-specific

causal principles that encourage perceptual processing of information about the movements of biological or inanimate objects as a whole (Gelman, 1990). Of course, if an individual has yet to acquire the principles that organize a given noncore domain, these considerations about selective attention cannot apply. Core domains facilitate learning about the domain because they have innate skeletal structures; the structures of noncore domains have to be learned from scratch (Gelman & Williams, 1997).

General processes like discrimination, or general purpose processing mechanisms like short-term memory, do not constitute domains any more than the process of applying rewrite rules, which is common to all formal systems, constitutes a domain of mathematics. Nor does a script structure constitute a domain. Scripts are analogous to the heuristic prescriptions for solving problems in mathematics, which should not be confused with the mathematical domains themselves (algebra, calculus, theory of functions, and so on). Still, information-processing limits on short-term memory can influence whether a given domain-specific problem is solved correctly. For example, although there is nothing in Gelman and Gallistel's (1978) counting principles that requires children to place items in a row and count from one end to the other, efforts to honor the one-to-one principle favor this kind of solution because one is less likely to make domain-relevant errors like the double-counting or skipping of items. In this case we can say that the principles potentiate some procedures over others, ones that can contribute to the generation of well-formed plans for solving the task at hand. Preschool children know that systematic left to right or right to left counts are conventional as opposed to required counting procedures. They accept skip-around counts as "okay, but silly, for counting" (Gelman, Meck, & Merkin, 1986).

How many domains are there?

Leslie (1994) identified a common objection to the idea that cognitive development benefits from sets of innate, domain-specific, learning-enabling structures: "There could turn out to be too many domains" (Leslie, 1994, p.120). In this regard, it is important to point out that there is nothing in our definition of a domain that requires that a domain-specific knowledge structure be built on an innate foundation. To say that some of the many domains that people can acquire have an innate basis is not to say that all domains are core domains. Core, or innate, domains are universally shared because they are developed from a common set of existing skeletal structures. Given their presence, learners already have the wherewithal to find and assimilate relevant data. If the data are present in the surrounding environments, learning can proceed without the explicit help of others. In this sense, learning can take place "on the fly", as the learner encounters domain-relevant inputs to assimilate to an existing structure. Because learning in a noncore domain must proceed without the benefit of even a skeletal structure, the acquisition of knowledge in the domain must be more difficult. Given the wide variety of noncore domains and the different opportunities for encountering domain-relevant learning inputs, we should expect different people to master different noncore domains. In addition, the number of noncore domains we become expert at will probably be limited in number. It is unlikely that there will be many Leonardo da Vinci's among us.

Our move to answer the question of "how many domains are there" in the context of the distinction between core and noncore domains is akin to the linguistic distinction between closed and open class morphemes. All who acquire their language as young children share knowledge of the small set of closed class of morphemes in their language. These morphemes serve the capacity to generate utterances that honor the combinatorial rules underlying the morphology and syntax of their language. The open class of morphemes includes all learned and to-be-learned nouns, verbs, adjectives and adverbs—a potentially infinitely large class. Different individuals can master different examples and different numbers of entries in the open class. Similarly, the set of noncore domains is potentially very large and can vary from individual to individual. In contrast, the set of core conceptual domains is relatively small, with their underlying structures being shared by all.

What is innate for a core domain?

When I say that core domains benefit from the presence of innate structures, I find it helpful to use the metaphor of a skeleton. Were there no skeletons to dictate the shape and contents of the bodies of the pertinent mental structures, then the acquired representations would not cohere. Just as different skeletons are assembled according to different principles, so too are different coherent bodies of knowledge. Skeletons need not be evident on the surface of a body. Similarly the underlying axiom-like principles that enable the acquisition of coherent knowledge need never be accessible. Most importantly, skeletons lack flesh and some relevant body structures. Therefore, in no way can they be said to represent full-blown knowledge of their domain; instead they are potential structures, ones that can contribute to the epigenesis of their respective flesh and structures as they interact with the kinds of environments that have the potential to nourish such development.

If we postulate core domains, we achieve an account of the fact that infants respond to structured data as opposed to simple punctate sensations. Because application of even skeletal structures means that the class of relevant data will be relational and overlap with the abstract principles that lime the domain. That is, it is not the case that infants will be confronted with William James' blooming buzzing confusion of punctate bits of uninterpretable sensations. Instead, it is an environment with things "out there", things to find and learn about. Different

implicit knowledge structures should encourage attention to and exploration of different kinds of structured data and the assimilation of these helps nourish the coherent growth of these nascent structures.

A wide range of findings about very young infants' perceptual and conceptual competencies lend support to this shift in view of what kind of perspective the infant has. For example, 1-month-old infants' sucking behaviors reveal an interest in speech as well as the ability to make categorical speech-sound discriminations (Fernald, 1985; Juscyck, 1996; Mehler & Cristophe, 1995). Seven-month-olds separately categorize replicas of animals and nonanimals, as revealed by their reliable tendency to touch items within one category before switching to explore those in another category (Mandler & McDonough, 1996). In related findings, Leslie (1995) has shown that 6- to 8-month-old infants are surprised when an inanimate object moves without assistance, but not when an animate object does so. Baillargeon (1995) demonstrated that even younger infants look longer at "impossible events" (in which objects appear to violate physical laws) than they do at "possible events". For example, in one of her studies 5-month-old infants respond in ways consistent with the belief that one solid object cannot pass through another (Baillargeon, Spelke, & Wasserman, 1985). Infants were first shown a screen as it rotated towards and away from them through an 180° arc, from flat to upright to flat and back again. When their interest in the moving screen declined, that is, when the infants habituated, they were shown a new display. This consisted of an object that was held to the left side of the screen, and then moved behind the screen once the infant had looked at it. At this point the screen once again rotated toward and away from the infant, either stopping at 110° or continuing all the way through the 180° arc (thanks to the use of trick mirrors and invisible doors). From an adult's perspective, the latter event would look like an impossible event where the screen seems to pass through a known hidden object. Because infants preferred to look at this event, we can infer that they too thought the event was impossible. Otherwise, there is no reason for them to have treated it as a novel event, given that they habituated to demonstrations of the 180° arc.

Infants also develop expectations for the number of things or events they are shown, including heterogeneous objects or drum beats, moving dots on a monitor, or events like a rabbit jumping (Starkey, Spelke, & Gelman, 1990; van Loosbroek & Smitsman, 1990; Wynn, 1995). They look preferentially longer at a 2-item or 3-item heterogeneous visual display depending on whether they hear 2 or 3 drum beats (Starkey et al., 1990), and are surprised when the number of objects they encounter changes as a result of unseen, surreptitious additions and subtractions (Wynn, 1992, 1995). Some authors (e.g. Cooper, 1984; Simon, Hespos, & Rochat, 1995; Xu & Carey, 1996) resist the idea that these findings reveal a number-specific structure at work. Even if we accept their position that infants *only* use a one-for-one category mapping rule, the description of the primary data is still abstract and relational. Infants surely are not responding to bits of sensory input, punctate bits of light, color, and so on; otherwise they would not habituate in experiments where the items change on every trial.

To summarize, the first principles that constitute a skeletal structure feed the epigenesis of the respective structures. They do so by focusing attention on inputs that are relevant for the acquisition of concepts and providing a way to store incoming data in a coherent fashion. In other words, the active use of existing nascent structures enables the search for and zeroing in on domain-relevant learning paths. Relevant inputs, that is, ones that map structurally to existing mental structures, can then feed the coherent development of knowledge within their respective domains, the result being that still further examples of relevant data can be found, and so on. The interaction between structures of the mind and environment is bidirectional from the start.

The aptness of the skeleton metaphor is less than perfect. It carries the implication that all principles are in place before their respective bodies of knowledge are acquired. This is unlikely. In fact, it is possible that only some subset of principles of a domain serve as part of the initial skeleton. Furthermore, initial principles might even be replaced or expanded over the course of learning. An example of how encounters with the world can lead to learning about principles not contained in the skeleton of a domain comes from work on infants' ability to make inferences about an object's continued path. Whereas infants of four months of age or younger know that an object will move if it is struck by another one, they seem not to know how far it will go. It takes experience with the path of particular objects to shift from relying on quantitative expectations about the distance an object will traverse after it is hit. A salient example of the role of experience with moving objects comes from Spelke. She shows that, although infants learn quickly about the effects of gravity, they do not start out with implicit knowledge of its effects on falling objects (see Carey & Spelke, 1994).

Given the human capacity to map symbol systems to existing structures (Lee & Karmiloff-Smith, 1996), we should expect the nature of domain-relevant knowledge to expand, and even change, as a function of the kinds of symbolic experiences young learners encounter on the domain-relevant learning paths their environments offer. We return to this matter after a consideration of a question we are sure that many readers will be asking, namely, how can we use the term "learning" in the same context as the term "innate"?

How can core domains be both "innate" and "learned"?

Those who endorse a variation of the empiricist theory of knowledge acquisition treat the terms "innate" and "learned" as opposites. This is because the theory takes it as given that infants are born with a tabula rasa and that all knowledge is learned from scratch. Learning about the world proceeds as a result of the

ability to form associations, initially between sensations and responses that occur closely together in time and/or space. The more frequent these contiguous pairings, the more likely associations about given sources are formed in memory. Clearly, such a definition of the nature of concept development does not fit with ones that assume there are innate sources of some of the knowledge that will be acquired. This is especially so for turn-of-the-century determinist theories of knowledge wherein it was assumed that innate contributions are always in a mature steady state, waiting to generate perfect and nonvariable performance, no matter what the context. In such a theoretical context it is true that the idea that knowledge is learned is incompatible with the idea that it is innate. However, a long time has gone by since the turn of the century. Determinism is a very outdated theory in present-day biology. The explosion of work and theory in developmental biology, ethology, animal cognition, behavioral genetics, and evolutionary psychology has generated new ideas about acquisition, so much so that a new theory of learning has evolved, one in which the concepts of *innate* and *learned* both play critical roles in the account of how species-specific knowledge is acquired as the learner interacts with relevant environments. Gould and Marler (1987; Marler, 1991) even write about the "instinct to learn".

The skeletal principles of an innate domain of conceptual development need not be represented within the system in a symbolic or linguistic form. Most likely they are first represented within the structure of the information processing mechanisms that assimilate experience and direct action (cf. Karmiloff-Smith, 1992). Marr (1982) presents many cases where the algorithms by which the visual system processes visual input incorporate implicitly various principles about the structure of the world. Gallistel (1990; Cheng & Gallistel, 1984) argues that the principles of Euclidean geometry are implicit in the mechanisms by which the rat constructs and uses a map of its environment. Knudsen's (1983) work on the development of the tectal circuitry for representing the angular positions of distal stimuli apprehended by different sensory modalities in the barn owl provides a clear example of how a principle can be implicit in a developmental mechanism. Implicit in the mechanism that controls the development of tectal circuitry is the principle that the spatial matrix for experience is unitary and transcends sensory modality. An object cannot have one location in the space apprehended through the visual modality and a different location in the space apprehended through the auditory modality. Thus, when the mapping of visual locations is experimentally put out of register with the mapping of auditory locations, the maturing circuitry reorganizes so as to bring the mappings back into register.

These theoretical and related empirical developments mean that we no longer can tie the definition of the term *learning* to one class of theories. Instead it is important to recognize that there are competing theories of learning, each with its own assumptions and therefore theoretical primitives. True, a theory that posits innate structures is unlikely to be a variant of an empiricist theory of learning, but this does not rule it out as a theory of learning. It is a theory of learning if it assumes that learners must interact with relevant environments and build knowledge representations as a function of these. The idea that learning in core domains is privileged, owing to the presence of innate, skeletal mental structures, clearly is not a variant of the biological theory of determinism. Nevertheless, many in the field of psychology write as if determinism is the model underlying the work of those who are trying to detail the learning mechanisms that provide enabling constraints for some domains of knowledge. Nelson's (1988) critique of "constraints theory" provides an illustration of this usage within the field of developmental psychology: "A true constraint would be manifested in all or none type responses; . . . If the constraint is universal (cognitive or linguistic), all children should follow the pattern . . . If they are innate, they should apply from the beginning of the language learning process" (pp. 227–228). Plunkett adopts a similar view when he reviews reasons for rejecting domain-specific origins of knowledge (Plunkett & Marchman, 1991; Plunkett, this volume). Such conclusions are not warranted. This is because the terms "innate" and "learned" are not opposites on a priori grounds. Theoretical terms do not stand alone as regards their meanings; they are imbued with theory-laden assumptions. Whether a pair of terms are opposites is dependent on the theoretical frame of reference in which they are used. Given a rational-constructivist theory of learning, and the related shift in meaning, the terms "innate" and "learned" are no longer opposite in meaning. The shift in meaning of terms goes hand in hand with the shift in the theory about learning. There is no reason to think this is less true for theories in psychology than it is for those in biology, physics, and mathematics, and thus for terms like *learning* as opposed to *energy*, *matter*, and *number*.

Differences in the intended meaning of how a term is used within a discipline can provide clues that there is either an ongoing theory change or that qualitatively different theories are existing side by side. Gelman and Williams (1997) develop this theme with respect to the notion of *learning*. For a large number of psychologists, the term *learning* is embedded in a version of Empiricism and its assumption of a blank slate at birth. Within this theoretical frame of reference, it is true that terms like *biological constraint*, *innate* and *instinct* have meanings that are opposite to *learned*. As the everyday meanings of such terms are commonly paraphrased as *restricted*, *required*, *forced*, and pitted against words like *acquired*, *learned*, *experienced*, *educated*, we are not surprised when we are asked "how can a domain be both learned and innate?" This is a straightforward question, if it is posed within the framework of association theory. But it becomes a nonquestion within a theory that recognizes that innate mental structures include learning requirements. As our account is fundamentally committed to the premise that concept learning is what happens as a function of experience, it is a learning account. It is best classified as a rational-constructivist theory, as opposed to an empiricist or associationist theory, as regards its foundational assumptions. Also,

it takes as given that learners must encounter domain-relevant experiences, even for core domains. Without the opportunity to interact with and store relevant data, there cannot be a forward moving construction of the knowledge of a domain, be it core or noncore in kind.

What constitutes learning in a domain—core or otherwise?

Like others we assume that learning leads to the build up of domain-relevant knowledge and relevant characteristics of such knowledge. Gelman and Williams (1997) couch their account of learning in terms of the kinds of mental learning tools that can contribute to the active construction of knowledge. They argue that the mind favors *structure-mapping* as the fundamental learning process (Gelman & Williams, 1997). Given the mind actively applies its existing structures to find examples of structured data in the environments with which it interacts, learning in core domains is privileged. Skeletal structures provide the beginning learner with the wherewithal to find and map inputs that are examples to available structures. Even though initial mental structures are skeletal in form, they nevertheless are available structures. For learning with understanding to occur in a noncore domain, the mind has to acquire both the structure and the domain-relevant data base of the novel domain. Therefore nascent skeletal structures help learners move onto relevant learning paths, ones that have the potential to support the mind's everpresent structure-mapping proclivities.

In sum, our mind's ever-present tendency to find and map inputs to our existing mental structures benefits from structure-mapping as a foundational learning device. This enables the recognition, identification, and assimilation, of relevant inputs with the result that there will be attention to the relevant learning paths in the environment that can nurture the acquisition of a coherent, data-rich, organized body of knowledge. In turn, the acquired knowledge base can foster upgrades in the range of inputs and specification of domain-relevant inputs. In these ways skeletal structures serve as initial, but not determining, domain-specific engines of learning for young minds.

The ability to achieve a structural map is as critical for learning in a noncore as it is in a core domain. However, learning in noncore domains can be handicapped for a straightforward reason: There is no domain-relevant structure, not even a skeletal one, to start the ball rolling. This means that the mental structures have to be acquired de novo for noncore domains like chess, sushi making, computer programming, literary criticism, and so on. In these cases, learners have a twofold task. They have to acquire both domain-relevant structures and a coherent base of domain-relevant knowledge about the content of that domain (see also, Brown, 1990). It is far from easy to assemble truly new conceptual structures (see, for example, Carey, 1991; Chi, 1992; Kuhn, 1970) and it takes a very long time. Something resembling formal instruction is usually required and often this is not effective unless there is extended practice and effort on the part of the learner (Ericsson & Smith, 1996). Efforts to provide domain-relevant instruction in noncore domains must recognize and overcome a crucial challenge: Learners may assimilate inputs to existing conceptual structures even when those inputs are intended to force accommodation and conceptual change (Gelman, 1993, 1994; Slotta, Chi, & Joram, 1995). That is, learners may fail to interpret novel inputs as intended and instead treat the data as further examples of the kinds of understanding they have available. As discussed later, the risk for this happening is especially high in mathematics classes.

As learning can and does take place in noncore domains, it must be that there are learning tools that serve as mental stepping stones. In this regard, it is important to keep in mind the fact that humans learn symbolic and notational systems. I also note that imitation and analogical learning can function as examples of structure creation and structure mapping, respectively, if care is taken to assure that the learner attends to and assimilates the structure of the offered data bases (Brown & Campione, 1996; Gelman & Lee Gattis, 1995; Piaget, 1951). For example, young children know that there are different rules for different notation systems, even though they have much to learn about the details and conventions for these (Brenneman, Massey, Machado, & Gelman, 1996). They are also pretty good at imitating what they see others do and at using basic conversational rules (Siegal, 1991). Together, these structural tools can be viewed as learning tools for identifying what aspects of new information is relevant and what information about different domains should be treated as coming from different categories, events, and so on. They afford the mind ways of identifying relevant novel data sets and setting up new memory drawers in which to collect and keep together in memory the new domain-relevant knowledge. Over time, these memory drawers will start to fill up, most likely in an unorderly way, given the lack of understanding about them. But, with continued interaction with inputs and informal or formal instruction about these, there will come a point where we will, so to speak, look into our messy memory drawers, and organize them in a systematic way (cf. Karmiloff-Smith, 1992). How and when this happens are key research questions that are especially likely to inform understanding about the shift from novice to expert levels of knowledge.

What to do about frequency effects?

We know that young children are sensitive to the frequency with which they encounter examples of a relevant data set, including the frequency of irregular verbs (e.g. Marcus et al., 1992; Plunkett & Marchman, 1991) and relevant attributes of concept exemplars (e.g. Macario, 1991). Indeed, there is good evidence that animals and humans of all ages keep track *automatically* of the frequency of relevant events and objects (Hasher and Zacks, 1979; Gallistel, 1990). For example, Hasher and Zacks (1979) showed 5- to 8-year-old children a series of

pictures, in which each picture appeared 0–4 times. Children in all age groups were highly and equally successful at reporting how many times a picture had been shown, even though they did not receive any instructions to keep track of this information. Similarly, robust abilities to pick up frequency information about objects or events abound. Hasher and Zacks (1984) have documented frequency learning across populations (college students, learning-disabled children, depressed and elderly persons), as well as across a wide range of variable-frequency materials (letters of the alphabet, familiar words, surnames, and professions).

Some might conclude that data such as the preceding provide especially strong support for an associationist account of learning, in particular, and domain-general learning mechanisms in general. Neither conclusion is warranted, given that the proposed computational device computes one and only one kind of data, frequency. As regards the status of association theory, it is well to keep in mind that the theory assumes that association strength builds as a function of frequency and contiguity. Within associationism, frequency (as well as contiguity) is a condition for the formation and increase in strength of a given association. The more frequent a given pairing, the greater the strength of the association stored in memory. Certain associations are stronger than others because they had the benefit of more frequent encounters with particular pairings of stimuli, and/or short delays between the CS, UCS, longer or larger rewards, and the like. Note, that there is nothing about the associative strength that represents the values of the conditions that contributed to its growth. The idea is that frequency and contiguity work together to determine associative strength, not create representations of the values of these factors. If associative strengths do not contain information about the frequencies that contributed to them, it follows that frequency information cannot be recovered from them. The fact that the mind does register the frequency with which a class of objects or events occurs is a real problem for association theory. If frequency is not encoded by associative strength, associations cannot be the mental device that keeps track of frequency *per se*. It must be that there is some other way that the mind is able to represent the frequency data it encounters as frequency *per se*.

If we are to argue that the mind does, in fact, keep track of the frequency of relevant learning events, then we need a mechanism to accomplish this. This is what motivated Gelman and Williams (1997) to conclude that the mind has a frequency-computing learning tool that is called in to play by a domain when frequency is relevant information for that domain. Our idea that there is a frequency-computing device allows us to make sense of the data that are used to favor feature and prototpye theories of concepts over theories that include the notions of essences, conceptual coherence, and core domains as explanatory hypotheses. The assumption is that a domain can engage a frequency counter to keep track of how often it encounters domain-relevant exemplars or characteristics.

The fact that more than one domain can make use of frequency data does *not* license the conclusion that a frequency-computing learning tool is domain-general.

Discussions of domain-general learning processes are treated as content neutral. Even if different domains call on a frequency-computing learning tool, the stuff that is counted is given by the principles of the domain. Cheng and her colleagues (Cheng, 1997) refer to domain-specific abilities to compute frequencies that index relevant and irrelevant covariations for particular cases of knowledge. Others appeal to the use of a frequency counter as part of their explanation of how children learn to classify moving objects as animate or inanimate based on the causal conditions of animate versus inanimate motion (Gelman, 1990; Gelman, Durgin, & Kaufman, 1995). Keil (1995) has proposed that learning about the structures of "concepts in theories" is supplemented by feature tabulation processes. Schwartz and Reisberg (1991) suggest that we may need a three-part theory of concepts, in which "concepts are represented by a prototype, some set of specifically remembered cases, and some further abstract information" (p. 391), where the parts all interact to accomplish correct similarity judgments and inferences. In our account, the recorded knowledge of frequencies and contingencies underlies subjects' ability to answer questions in ways that make them look like they learn prototypes and some salient domain-relevant exemplars. More generally, our account provides a way to reconcile these response patterns with the

compelling arguments against defining feature and prototype theories (Armstrong, Gleitman, & Gleitman, 1983; Fodor & Lepore, 1996). High-frequency features or exemplars data are more memorable. Because low-frequency encounters are less memorable, they are less likely to be accessed in tasks designed to encourage subjects to provide "defining" features for a given concept. Nevertheless, if the example of the concept yields a structural map to the domain in question, the item or event will be accepted as one that belongs to the concept in question. Frequency computations provide heuristic value, they support reasonable guesses about the identity of novel instances. But, in the end, they do not determine concept identification. This is a job for structural-mapping (see also Holyoak & Thagard, 1997).

How can knowledge be innate and yet variably applied?

Some authors argue that findings of early conceptual competence are obtained under too limited a set of conditions and therefore do not justify the attribution of principled knowledge about objects and numerosity. For example, Fischer and Bidell (1991) take the fact that infants fail to reveal comparable knowledge on Piagetian tasks as compelling reason to reject Baillargeon's and Spelke's attributions of conceptual competence for objects to the very young. Systematic within and across condition variability in the extent to which performance conforms to abstract principles is consistent with traditional learning and developmental theories in which unprincipled "habits" are acquired prior to the induction of principles.

Contrary to widespread assumption, wih rare exception, any genetic program carries with it extensive requirements for interactions with those kinds of environments that can nurture, support, and channel the differentiation of adult structure. In the absence of those environments, the program will almost certainly fail. The same is surely true for skeletal mental structures; the existence of a primordial input-structuring mechanism does not guarantee that related knowledge will spring forth full-blown the moment the individual encounters a single example of the requisite environment. Without opportunities to interact with, learn about, and construct domain-relevant inputs, as well as to practice components of relevant action plans, the contributions of skeletal structures will remain unrealized, or will lead to atypical developments. Learners must encounter opportunities to interact with and assimilate relevant supporting environments (c.f. Scarr, 1993). It also follows that variability is a characteristic of any learning, be it about core domains that benefit from skeletal structures or noncore domains that do not (cf. Siegler & Shipley, 1995). It therefore behooves us to consider more carefully how one understands systematic cross-task variability in different accounts of concept development.

Gelman and Greeno (1989) point out that there are a number of systematic sources of variability that can mask conceptual competence, including limited procedural and interpretative competence. As Gallistel and Gelman's (1992) competence model of preverbal counting makes use of mechanisms whose outputs are inherently variable, it is also necessary to find ways to relate details of variability at this level to choices of models. Gelman and Greeno (1989) expand on their initial proposal (Greeno, Riley, & Gelman, 1984) that competent plans of action require the successful integration of *conceptual, procedural,* and *interpretative* (utilization) competence. A competent plan of action must honor the constraints of conceptual competence. For example, for a plan for counting to be competent, it must incorporate the constraints of the one-to-one counting principle. The plan must not embrace component acts of double tagging, item skipping, or tag repeating. Additionally, the plan has to be responsive to constraints on the interpretations of the task setting, instructions, domain-related terms, conversational rules, and so on. The limited development or misapplication of setting-relevant conversational rules can lead to faulty plans of action in a given setting and therefore variability in success levels across studies or tasks. One example of this is illustrated in Gelman et al.'s (1986) use of the "Doesn't Matter" counting task that asked children to count a row of items in a novel way.

The Doesn't Matter task begins when the experimenter points to an object that is not at an end of a row of items and asks the child to make that object "the one" and count all of the objects. To accomplish this, a child has to skip back and forth over the items while counting, switch the designated item with one that is at an end, or count as if the row of items were in a circle. Interestingly, very young children who were given a chance to count a row of items before they started the Doesn't Matter task did more poorly than children who had no pre-test counting experience. Inspection of their error patterns on the experimental task revealed that the latter group tried to find a way to meet the constraints of the new task while counting from one end of the array to another. It is as if they took their regular counting experience as an instruction to continue to count in the conventional way.

Conversational rule use also contributes a systematic source of variation to performance on the "How Many" task, one where individuals are to indicate how many items are present for different set sizes. This was illustrated in a study we reported in Gelman and Meck (1992). Adults were asked to participate in a control study for a task that is used with preschoolers. We scattered 18 counting blocks on a table and asked "How many blocks are here?". Subjects were encouraged to think out loud while figuring out "How Many" there were but they were not told to count. All subjects counted (sometimes using grouping strategies, e.g. counting by twos); only one repeated the last tag spontaneously. This means that almost no one stated the cardinal value after they had completed counting. This failure of subjects to answer the question we asked led us to use a second version of the procedure in a follow-up experiment. Now we repeated the "How Many" question if subjects had completed counting and did not repeat their last counting tag. Still, only 4 of 10 individuals answered in a straightforward way, that is by stating their last count tag when the question was repeated. The rest behaved as if they thought the question was odd. For example, one person laughed nervously and another said she assumed we were telling her that her initial count was wrong and so she recounted; another person said "Eighteen, I hope".

We expected these results on the grounds that repeating a question is a violation of the conversational rules adults follow, especially ones that converge on the maxim "do not repeat the obvious". Given that young children are likewise sensitive to this stricture (Siegal, 1991), it is reasonable to conclude that similar results reflect a common interpretative competence variable. This is important because much has been made of the variable ways that young children respond on "How Many?" tasks. For example, in one of her tasks Wynn (1990) asked 2- to 4-year-old children to count so as to indicate "How Many" items were in a given display. Children younger than 3-and-a-half tended to simply count or recite as many count words as there are items; they stopped without repeating the last tag, i.e. without stating the cardinal value of the set. When their correct counts led to a repeat of the "How Many" questions young children recounted. Fuson (1988) holds that even older preschoolers—sometimes as old as 5 years of age—are likely to repeat the last tag when asked "How Many", after either a correct or incorrect count.

Wynn (1990) also reports that her younger subjects (especially between 2- and 3-and-a-half years of age) solved her "give X" task by grabbing 2 or 3 items no matter what the set size (other than one). Only "Non-Grabbers" counted out

the requested number of items. Wynn concluded that "Grabbers" are especially disinclined to repeat the last tag after they count, doing so on only 26% of their correct count trials. In contrast, the mean percentage of cardinality answers of her "Counters" was 78%. As the tendency for children to give the cardinal answer after their count shifts abruptly at 3-and-a-half years—the same age that separates "Grabbers" from "Counters"—Wynn concludes that the younger children do not have a principled understanding of counting. Her idea is that they do not understand that counting is related in a principled way to the cardinal value of the set. This is unlikely given that adults behave in the same way. As no one would conclude that adults do not have a principled understanding of the count numbers, we should entertain the hypothesis that the seemingly straightforward "How Many" task is not especially good for assessing principled understanding of the principles of counting and their relationship to principles of addition and subtraction. This is why there has been a renewed effort in my lab to develop new counting and arithmetic tasks that are suitable for use with very young children (see Gelman, 1993).

The Gallistel and Gelman (1992) model of nonverbal counting illustrates how there can also be systematic variability that follows from some aspects of the operation of the machinery in whose structure the implicit principles of the conceptual competence resides. In our model, the preverbal counting mechanism generates mental magnitudes to represent numerosities; there is trial-to-trial variability in the magnitudes generated to represent one and the same set size; and this variability obeys Weber's law, that is, the standard deviation of the distribution increases in proportion to its mean. Given an additional systematic source of variability, an increasing tendency to lose track of what has and what remains to be counted as set size increases, it is likely that the spread on the distributions as set size increases is even wider than predicted from the Weber law. This is important in understanding a potent within-task source of systematic variability in children's numerical performance, the effect of the set size. It is especially pertinent to discussion of the systematic effect of set size on the tendency of infants and young children to respond correctly to the numerical information in a display.

To date, demonstrations of infants' ability to use numerical information have been limited to set sizes of 3 to 4. This fact has encouraged many to conclude that infants use perceptual mechanisms in lieu of mechanisms that embody implicit numerical principles. The favored perceptual mechanism is "subitizing", an example of a process that is assumed to allow subjects to make discriminations between set sizes without any implicit or explicit understanding of numerical principles (e.g. Cooper, 1984; Cooper, Campbell, & Blevins, 1983; Sophian, 1994; von Glaserfeld, 1982).

The preference for a subitizing account of how infants respond to variations produced by different set sizes is tied to studies of the reaction time adults require to state the number of dots in an array. Over the entire range of numerosities, the greater the numerosity, the longer the reaction time, but the first few increments in reaction time per additional dot in the display are smaller. (For reviews, see Gallistel & Gelman, 1992; Mandler & Shebo, 1982). As the slope of the reaction times function in the small number range ($N < 5$) is apparently shallower than in the large number range, it is commonly assumed that different processes underlie the responses to the small and large sets, subitizing and counting, respectively. If one yokes infants' failures on larger sets to the assumption that a counting mechanism is needed for larger set sizes, it follows that infants are limited to the use of a subitizing process. This would allow infants to succeed with very small sets but make it impossible for them to succeed on larger sets. On the subitizing model, the ability to discriminate threeness from twoness is akin to the ability to discriminate treeness from cowness; unlike counting processes, it does not depend in any way on numerical principles. There are several problems with this line of reasoning.

Conclusions that infants use a perception-only "subitizing" mechanism are based in large part on a methodological decision to score infants' numerical discriminations as correct (exact) or not, rather than looking at the variance in errors that are produced for larger set sizes. This method is unable to determine whether errors are due to an inability to use a preverbal counting process, or instead to increases in inherent variability. Thus, the claim that infants cannot deal at all with larger numbers is problematic. To distinguish between these alternatives, it will be necessary to find ways to obtain infants' estimates of variability as a function of set size. This has not yet been done, but corresponding studies have already been done with animals that reveal an ability to use set sizes much greater than 3 or 4. Because the infant data that do exist in other areas of numerical reasoning map well onto the animal data, Gallistel and Gelman (1992) have proposed that infants use a mechanism that is like the animal counting model developed by Church and Meck (1984).

Core domains and cultural variation?

Although different cultures use different lists and although older individuals might work with numbers in their head and use larger values, the underlying structure of the reasoning is the same. Different count lists all honor the same counting principles (Gelman & Gallistel, 1978) and different numbers are made by adding, subtracting, composing, and decomposing natural numbers that are thought of in terms of counting sets. The mathematical operations involved are always addition and subtraction, even if the task is stated as a multiplication or division one. In the latter case, people use repeated addition and subtraction to achieve an answer. Those who have learned to count by multiples of one, e.g. by fives, tens, fifties, hundreds, etc., are at an advantage because they can count and add faster than if they had to count by one (Nunes, Schliemann, & Cararaher, 1993; Vergnaud, 1983). This commonality of structure across tasks and settings

is an important additional line of evidence for the idea that counting principles and some simple arithmetic principles are universal. So too are the cross-cultural studies of "street" arithmetic.

Variations in performance levels and time to learn the count list are systematically related to schooling, the degree to which numbers are used in the everyday activities of a culture, what functions the count list serves, and the degree to which the base-10 structure is transparent in a given language system (e.g. Miller, Smith, Zhu, & Zhang, 1995; Saxe, 1979; Zaslavsky, 1973). For example, in Chinese, the words for 11, 12, 13, . . . , 20 translate as 10-1, 10-2, 10-3, . . . , 2-10s, 2-10s-1, 2-10s-3 . . . , 3-10s-1 . . . , etc. English count rules are not as transparent in the same range; consider the counting strings twelve, thirteen, fourteen, fifteen, and twenty, thirty, forty, and fifty. Miller et al. (1995) obtained the predicted interactions between age and range of count words on rate of learning. They found no differences for very young children learning to count in Chinese or English. That is, the number of count words learned was comparable. So too was the ability to use them to solve simple numerical problems. In contrast, Chinese-speaking children learned the teens more rapidly than English-speaking children. These are especially important findings for they illustrate the idea that common underlying conceptual structures can exist despite notable differences in how these play out in different cultures.

Those committed to the idea that the ability to learn about the natural numbers is culture specific might point to studies done in Africa and the South-Sea Islands (e.g. Menninger, 1969). The claim is that there are communities who cannot count, mainly because they use a small number of count words or hand-body configurations. However, the presumed limited ability to understand counting could be an artifact of cultural taboos against counting familiar objects, like cattle, houses, and children (Gelman & Gallistel, 1978). Some additional support for this hypothesis was obtained when, during a stay in Israel, my colleagues took me to visit a family who had emigrated from Ethiopia.[1] Rather than start with requests to count familiar objects, we decided to jump in and ask how to say various count words in Ahmaric. Questions about counting were addressed to the eldest male in the household and his answers in Ahmaric were interpreted by his Hebrew-speaking teenage daughter who had emigrated at an earlier date. By simply asking what was the word for a sample of "20, 31 . . ."; "100, 200, 301, . . .", "1000, 1001, . . .", etc., we ascertained that the father knew how to

[1] The visit occurred during June 1987 and was arranged by Dr B., a doctor much admired by the Falasha community. Others in the interview group were Professor Iris Levin, Tel Aviv University, and Dr Shaul Levin. Questions were addressed to the eldest male in the household; our interpreter was a teenage daugther who had emigrated ahead of other members of her family and already knew Hebrew. The "interview" was embedded in a conversation over tea that lasted about 45 minutes to an hour. The conversation took place in a combination of Hebrew, Ahmaric, and English. As it was the Sabbath, we did not write or record during the interview. Questions were prepared in advance and we wrote down our joint memories of anwers immediately after we left the family.

count verbally well into the thousands with a base-10 generative counting rule. This line of questioning stopped when we were given the Hebrew word for a million. No comparable word existed in the father's Ahmaric count vocabulary; he explained that this was because there were never that many things to count before he arrived in Israel. This led to discussions about what one counts. It was introduced with an open-ended format and then moved to an inquiry about specific kinds of items. When we asked if one counts children, the teenage daughter interrupted "You never count children. It's not done. . . . Well, except maybe in the hospital—when a doctor asks a pregnant woman".

It is true that some languages only have two or three count words. It does not follow, however, that the people who use these languages cannot count in a principled way, as is often suggested (e.g. Andrews, 1977; Menninger, 1969). The Bushmen of South Africa are a case in point. They indeed have but two separate count words. However, this does not keep them from counting at least to 10. They manage the latter by using the operation of addition to generate terms that represent successive larger cardinal values. For example, the word for eight translates as "two+two+two+two" (Flegg, 1989). Of course, this is the very same addition solution that plays so significant a role in "Street Mathematics". Thus, despite the notable differences in the particular verbal counting solutions that different cultures embrace, there is overlap at the structured, counting principle level.

There is nothing about the structural description of the counting principles that requires counts to be the tags used in the service of counting with understanding. Some cultures use hand configurations and body positions as the tagging entries in their count list (Zaslavsky, 1973). The Oksapmin of New Guinea provide us with an especially compelling case of using sequential positions on the body as counting tags. Their count list is made up of 29 unique entries that starts with the right thumb, which corresponds to "1", moves to the right index finger to "2" and so on (Saxe, 1979). Tagging continues to the right, up through points on the right arm and shoulder, around the outside of the head, down the left shoulder and arm, and ending with the left thumb which corresponds to "29". We cannot claim that these count lists are not "real" count lists because they are "concrete" and not "abstract" (i.e. verbal). Saxe (1981) found that the Oksapmin use their lists in a principled way. He first told the participants in his study about people in a far-away village who started their count on the left side of their bodies instead of the right side. Then he continued with the fact that men from theirs and the far-away village counted sweet potatoes, ending their counts at the same body part (e.g. left shoulder). Finally, he asked who would have counted more potatoes, themselves or those from the other far-away village? If they had said that the men from both villages counted the same number, we could conclude that they were not using body parts as arbitrary symbols in an ordered list. However, the participants did answer appropriately, depending on which villager's system was used. We can conclude that they were able to use both counting and reasoning principles.

Further evidence for the worldwide use of counting and the arithmetic principles of addition and subtraction is presented in Crump (1990). Compelling examples are provided by studies of "Street Arithmetic". Reed and Lave (1979) found that Liberian tailors who had not been to school solved arithmetic problems by laying out a set of familiar objects (e.g. buttons, pebbles), or drawing lines on paper, and then counting them. Nunes et al. (1993) found that 9- to 15-year-old street vendors were able to indicate what a number of coconuts would cost by performing a chain of additions on known numbers. For example, a 9-year-old said "Forty, eighty, one twenty" when asked the cost for 3 coconuts at a price of 40 cruzeiros each. When another child was asked to determine how much a customer would have to pay for 15 of an item costing 50 cruzeiros each, he answered, "Fifty, one hundred, one fifty, two hundred, two fifty. (Pause). Two fifty, five hundred, five fifty, six hundred, six fifty, seven hundred, seven fifty" (p. 43, Nunes et al.).

Thus we see that when the focus is on the abstract level of structure, there are multiple lines of evidence that fit together to support the conclusion that skeletal principles of counting and arithmetic reasoning form a core domain. Similar conclusions are reached by others in their studies of biological classifications (Atran, 1994; Gelman & Wellman, 1991; Simons & Keil, 1995) and the animate-inanimate distinction (Gelman et al., 1995; Premack & Premack, 1995). This makes it possible for cognitive universals to live alongside culturally-specific interpretations (Boyer, 1995; Gelman & Brenneman, 1994; Sperber, 1994) and illustrates how a domain can be both innate and learned.

As skeletal principles give the young constructivist mind a way to attend to and selectively process data, they similarly contribute to the nurturing and development of the concepts that are related to the structure of the domain in question. No matter how skeletal these first principles may be, they still can organize the search for, and assimilation of, inputs that can feed the development of the concepts of the domain. Actively assimilated inputs help flesh out the skeletal structure. The more structured knowledge there is, the more it is possible for the learner to find domain-relevant inputs to attend to and actively assimilate to the existing structure. The positive feedback set up underlies the continual build up of the knowledge structure within the domain.

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