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14 First principles can support both universal and culture-specific learning about number and music

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There is a growing body of evidence that infants attend selectively to some fundamental aspects of number and music. Such findings suggest that attention to and learning about number and music are perhaps due to the presence of innate, skeletal principles in each domain. In our chapter, we develop this position while showing how it is consistent with the different ways that cultures support learning and development in specific knowledge areas. Pairing considerations of number and music enables us to show that domain specificity and cultural variation need not be treated as antithetical.

Whereas it is still common for scholars in some fields to assume that "primitive" peoples lack a concept of number (see the following discussion), there is wide acceptance of the idea that all peoples develop musical competence, mainly because the latter can happen without benefit of formal instruction, use of special symbol systems, or the need to represent abstract, relevant dimensions like pitch, key, harmony, rhythm, and so forth. Indeed, accounts of the evolutionary function of the human music capacity often include the idea that, in preliterate societies, music serves to efficiently organize information that cannot be written down. For example, Gardner (1983) describes a possible role for music in organizing religious rites and work groups in the Stone Age, and Sloboda (1985) hypothesizes that music provides a mnemonic framework within which the structure of cultural knowledge and societal relations is stored and communicated. Whatever the role of music in preliterate groups, Donald (1991) points out that these societies always have complex rituals based on some form of music.

In contrast to music, discussions of number are almost always paired with one version or another of the idea that, to become truly competent with

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numbers, one must learn a symbol system for counting, master the meaning of cardinal terms, and/or develop the abstract and logical abilities that underlie the capacity to think about and use numerical concepts. These contrasting beliefs about the underlying learning paths to musical and numerical skill could be paralleled by the claim that infants' ability to respond initially to music-relevant relationships in a sound sequence is based on the kinds of simple perceptual processes that support "primitive" cultures' development of complex, but nonabstract, music skills. The argument would continue that infants' and "primitives'" numerically relevant responses to number are likewise based on simple perceptual processes and therefore cannot be truly numerical. According to this view, real learning about number is different because it clearly must be based on more abstract processes, the use of logic, the ability to use language, and/or instruction (e.g., Saxe, 1989).

The claim that "primitive" people and young children are restricted to perceptual processes and therefore lack abstract numerical abilities, is less prevalent than it once was, especially in anthropology (e.g., Crump, 1990). Nevertheless, the claim is still made, especially in treatments of the history of numbers (e.g., Andrews, 1977; Beckmann, 1924; Dantzig, 1954; Ifrah, 1981/1985; Kline, 1972; Menninger, 1969) or when developmental theory is applied (e.g., Hallpike, 1979; McLeish, 1992). The widespread view is that very young children lack simple, nonverbal numerical concepts. Theorists much prefer to attribute data on early, preverbal, or "primitive" number use to some variant of a perceptual pattern detector or "perceptual intuition" (e.g., Cooper, 1984; Fuson, 1988; Klahr & Wallace, 1973; McLeish, 1992; Mandler, 1992). For example:

> Anthropological studies on primitive peoples . . . reveal that those savages who have not reached the stage of finger counting are completely deprived of all perception of number. Such is the case among numerous tribes in Australia, the South Sea Islands, South America and Africa. Curr, who has made an extensive study of primitive Australia, holds that but few of the natives are able to discern four, and that no Australian in his wild state can perceive seven. The Bushmen of South Africa have no number words beyond one, two, and many, and these words are so inarticulate that it may be doubted whether the natives attach a clear meaning to them. (Dantzig, 1954: 2)
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> In our own time, a few "primitive" peoples of Oceania, Africa and America are still at the "zero" degree of experience with numbers. Guided solely by their natural ability to recognize concrete quantities at a glance, they can conceive, discern, and designate only a single object or a pair, and so their numerical notions are limited to "one," "two," and "many." (Ifrah, 1981/1985: xii)
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> It is now well-known that infants within the first year of life can discriminate between sets of different small numerosities: . . . This kind of behavior . . . has played an important role in nativist theories of number development. However, from a Piagetian perspective a concept is far more than discrimination: It implies the representation of some commonality that has been abstracted from a set of exemplars. (Sophian, 1991/1992: 28–29)

> Even human beings, for whom the abstract activity of counting seems the most natural thing in the world, find it incredibly difficult to learn. One of the discoveries of 20th-century scientists (made independently by Montessori, Piaget, and Vygotsky) was that adults forget how gradual and time-consuming the process of learning to think in the abstract is. (McLeish, 1992: 8)

It is the very presumption that responding to and creating music neither requires abstract representational abilities nor formal instruction, whereas learning to use the number system does, which leads us to pair these domains. Accounts of initial learnings about number and music differ dramatically in the extent to which education is granted a causal role. Although it is generally assumed that learning about the music of a culture can proceed without formal instruction, the same is not true for learning about number. This difference provides us with a way to decouple the contributions of general learning and school-based, instructional processes from the contribution of innate, domain-specific principles to knowledge acquisition in a domain. For there is evidence that just as musical knowledge develops without benefit of formal instruction, so does knowledge about number. This parallel is one reason we propose that the acquisition of knowledge in both domains grows on a skeleton of innate, domain-specific knowledge.

In the following discussion we start with a crucial matter: a definition of a domain and a description of the innate principles that guide knowledge acquisition within certain domains. We briefly review why an assumption of *some* innate knowledge in a domain does not rule out the need for learning in this domain. These sections provide the foundation on which we build the thesis that learning about both number and music is facilitated, but not guaranteed, by the presence of skeletal, domain-specific principles. We next discuss why our account of principle-first learning is stronger than the learning account offered by Associationism. Finally, we return to the idea that innateness and cultural creativity are not opposites and indeed work together to guide the acquisition of human knowledge.

Defining domain specificity

We follow Gelman and Greeno (1989) and Gallistel (1990) by defining a domain of knowledge in much the same way that formalists do, by appeal to the notion of principles. A given set of principles, the rules of their application, and the entities to which they apply together constitute a domain. Because each set of principles constitutes a different structure, we can characterize a domain in terms of a set of interrelated principles that define entities and operations on them. In contrast, general processes such as discrimination or general-purpose processing mechanisms like short term memory do not constitute domains, any more than the process of long division or the American subtraction algorithm constitutes a domain of mathematics. Similarly, the process of musical transcription and the circle of fifths are not domains. Scripts, at least in the form in which they are often given, do not constitute domains; they are analogous to the heuristic prescriptions for solving problems in mathematics or creating a coherent musical composition. As such, these heuristics should not be confused with the mathematical domains themselves (algebra, geometry, theory of functions, and so on) or the specific genres of music to which they might apply (e.g., classical or jazz). In sum, the test for a conceptual domain is whether it can be characterized in terms of a coherent set of operating principles and their related entities.

We turn now to evidence that both number and music form conceptual domains. Our discussion of the number domain draws heavily on data indicating that infants respond to numerically relevant displays in a way that suggests the operation of certain arithmetic principles. We also answer standard criticisms of our approach as well as offer evidence against alternative interpretations of the data we use to support our position. Our approach to the music domain differs somewhat in that we rely on animal and neuropsychological data to support our claim that the acquisition of musical knowledge is in large part guided by domain-specific, rather than domain-general, skills. As in our discussion of number, we present an alternative account of musical development and the skills of infants. We then explain why our approach is more consistent with the acquisition data of the neurologically normal, human population.

About number

Counting is part of a number-specific domain because the representatives of numerosity (what Gelman & Gallistel, 1978, dubbed *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 numeron are in fact numerically equal and the set assigned a greater numeron is more numerous than a set assigned a lesser numeron. Or, principles of multiplication must be applied consistently both to whole numbers and fractions. It will not do to say that in both cases the product is always more than the two entities being multiplied because this is not true when two fractions are multiplied.

For a variety of converging reasons, Gallistel and Gelman (1992) conclude that infants' numerically relevant responses to sets of inputs are supported by a skeleton of nonverbal counting and related numerical reasoning principles. First, infants discriminate between the Ns in a display whether they are alike or not, stationary or not, and visual or auditory (Starkey, Spelke, & Gelman, 1983; van Loosbroek & Smitsman, 1990). They also prefer one of a pair of slides that depicts the number of household objects matching the number of drumbeats they hear – whether or not the interval between the beats varies

(Starkey, Spelke, & Gelman, 1990). Second, although these numerical abilities appear to be restricted to displays with small set sizes ($N \leq 3$ or 4), this limitation does not license the conclusion that infants' responses reflect their reliance on nonnumerical, perceptual processes. If this alternative were true, then it would be hard to explain how infants also respond correctly to the effects of addition and subtraction (Baillargeon, Miller, & Constantino, 1992; Starkey, 1992; Wynn, 1992).

Third, one need not appeal to the rich abstraction abilities that Piaget (1952) and others do to grant that the domain-specific principles we have just outlined underlie infants' abilities to respond to number. Counting mechanisms exist that pay no attention to surface characteristics of objects; in these cases there is no need for high-level classification abilities to render something akin to Russell's class of all classes. In fact, the Gelman and Gallistel counting principles are indifferent to item kind (Gelman & Gallistel, 1978; Gallistel & Gelman, 1990). All that is required is the ability to keep together a collection of separable things; one need not even notice the characteristics of these things. (See Shipley & Shepperson, 1990, for further discussion of this point.) Similarly, one does not have to use linguistic tags to honor the requirements of the counting principles of one-one, stable-ordering, and cardinality. One does have to assign one and only one tag to each item in the display, assign the tags in a stable order across trials, and have a way of letting the last tag represent the value of the set. These requirements are all met by Gallistel and Gelman's (1992) nonverbal counting model, one they use to account for both infant and animal data.

Additionally, the Gallistel and Gelman model offers a straightforward account of the findings that infants' ability to discriminate accurately between set sizes is restricted to small Ns, for it distinguishes between the tendency to tag exactly as many times as there are items to tag and the tendency to do this variably. Following Meck and Church's (1983) model of the animal data (which show some animals dealing with Ns > 50), Gallistel and Gelman assume that both the mean number of tags and variance associated with a given value of N increases as set size does. The variance associated with each N is due to two factors, one from counting errors and the other from the inherent variance in the representations rendered by the count-ordered quantities. Because the animal data show overlap in the distribution of variances for Ns as small as 4, the same could be true for another nonverbal species, the human infant. Unfortunately, the pertinent infant data regarding the degree of variability as a function of set size are not available. Therefore, it is premature to favor some nonspecified "perceptual apprehension" mechanism over a nonverbal counting model to account for the number data from infants.

Finally, when Gallistel and Gelman conclude that infants have innate knowledge of number, they definitely do not mean that the infants have access to this knowledge. Nor do they mean that it is represented in a symbolic form. Instead, the idea is that the principles that define a domain are represented within the structure of the information processing mechanisms that assimilate and direct action. Infants' tendencies to use their information processing systems lead them to attend to data that are related to the structures inherent in these processing systems. Doing so leads to the very conditions necessary for learning to progress in the domains outlined by these structures.

About music

In the domain of music, we can say sequences of sounds are perceived as music when processing is governed by mechanisms that attend to and code pitch sequences as being tonally (or harmonically) and rhythmically related. Our arguments about innate, principled attentional mechanisms in the music domain are more speculative than those we offer for the human number capacities, however, the kind of processing mechanism that could be involved here has been worked out for some songbirds. Marler (1991) discusses the innate learning preferences of songbirds and the mechanisms that underlie these preferences. He indicates that species vary in the complexity of their songs, the degree to which learning requires simple or complex inputs, how much they have to practice as juveniles, and so on. Similarly, songs vary with respect to the number of different musical notes they include, the number and length of note sequences, internal phase structure, and tempo.[1] Despite this variation there is a general specification across species for input that adheres to the tonality characterizing the songs of most songbird species (Marler, 1991; Nowicki & Marler, 1988).

Work on bird song learning has led to the specification of inputs that are relevant to learning about song. For example, the male white-crowned sparrow is born with a template for his adult song. But he will not grow up to sing that song unless: (1) during a critical period early in development, he is exposed to a sample of it; and (2) during his juvenile period he has an opportunity to practice singing and, therefore, to go through a lengthy trial-and-error period before settling on the song that matches the template. Although practice is required here, the bird does not have to hear any further inputs during the juvenile period. What was heard early in life, before the bird could sing, suffices to tune the template that provides feedback, much like auditory memories of a correct way to play the piano do as a student practices and improves a lesson.

That the musical development of human beings may also be guided by this type of domain-specific mechanism, rather than pure perceptual processes, is suggested by the case of an autistic man, NP. NP was able to reproduce a sequence of sounds on a piano after minimal exposure. His skill, however, was specific to tonal sequences (Sloboda, Hermelin, & O'Connor, 1985). He had difficulty reproducing an atonal sequence ("Whole tone scale" from Bartok's *Mikrokosmos*). Therefore, NP was not simply a human tape recorder, capable of playing back any sound sequence. It is highly unlikely that his skill resulted from a domain-general memory capacity. Otherwise he should have been equally able to reproduce tonal and atonal pieces. His advanced development in a specific area was most likely based on domain-specific principles that privileged inputs based, in part, on certain tonality relevant features. The case of NP strongly suggests that nature provides human beings with learning mechanisms that are attuned to certain features of environmental input. We are not as far along in specifying what these features might be as are those who study avian species, which is why our comments on this issue cannot help but be speculative in nature (but see Takeuchi & Hulse, 1993).

Perhaps some would argue that our universal skills for music grow out of our ability to use language; the two share characteristics, such as rhythm, prosody, and pitch contours. This is unlikely given evidence from comparative animal work, neuropsychology, and evolutionary theory and given the structural differences between the two types of input. First, we know that the relevant input for birds acquiring song is composed of both phonetic and tonal features (Marler, 1991) and that, at the neuronal level, cells that respond preferentially to the harmonic aspects of song have been located in the HVc (forebrain nucleus hyperstriatum ventrale, pars caudale) of the zebra finch (Margoliash & Fortune, 1992). And although tonality is not a necessary feature of the relevant speech input needed for a child to learn language, the case of NP suggests that there is reason to suspect that tonality serves an important role in the definition of relevant musical input for human learners. The idea that music and language are not part of the same system and that one is not dependent on the other is reinforced by cases, including that of NP, in which music and language functions are dissociated. For example, a patient may retain musical functioning in the context of a severe aphasia and an autist may possess musical skill in the context of a subnormal IQ and poor language functioning (Gardner, 1983; Sloboda, Hermelin, & O'Connor, 1985; Winner, 1982).

Those who theorize about the evolutionary origins of musical and linguistic skill offer further reasons to treat these as separate capacities. Donald (1991) reviews Darwin's ideas on this matter and adds his own insights. How the human capacity for song arose from primate ancestors is a matter of more debate (see Sloboda, 1985), so we concern ourselves here with how music and language evolved once they were established in some form in the human being. According to Darwin, rudimentary song was a precursor to language. Control of the voice for communication of certain emotional content was first shown in the prosody of rudimentary song. This early prosody served as the basis for the capacity to produce melodic and harmonic song as well as the prosodic features of speech. Donald notes that improvements in voluntary control of prosody by the vocal apparatus would have formed a basis for phonetic control as language developed. However, he continues, although music and language might have a similar origin in rudimentary song it does not follow that they are part of the same system. Donald draws attention to the fact that musical skill is separable from verbal skill (Gardner, 1983). Given that aphasias result (nearly always) from damage to the left hemisphere whereas aprosodias and amusias result from damage to the right, he concludes that "language and rudimentary song are not aspects of a single system" (p. 40).

Finally, we know that the rules about the relationships between and among entities in music are quite different from those that govern the production of language. True, "parentese" (the speech adults address to young language learners) and music are similar on certain levels. Both have wide pitch ranges, dynamic contours, and rhythmic qualities. However, the structural differences between the two cannot be ignored. Music is based on contours provided by the relationship between discrete notes, whereas infant-directed parentese is characterized more by pitch glissandi within and between discrete words (see Fernald & Mazzie, 1991, for examples). Also, the varied rhythmic aspects of musical input are structured by a steady, underlying beat whereas the rhythms of speech are not. Additionally, we know that the physical characteristics of phonemes vary as a function of their context (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). For example, the actual "b" sound depends on which phonemes come before and after. In music, tones are defined by their frequency so that context does not affect how middle C (or any other note) is formed and produced. These differences are reflected in the fact that it is easy to specify the note that sounds like middle C on the piano but not at all easy to specify the phoneme that sounds like *ba* across the different words that share this same speech sound.

Because both speech and music are temporally arranged sequences of sound characterized by prosody, rhythm, and contour, it makes sense that some processing similarities would occur. For example, infant attention to phrase structure occurs both for music (Krumhansl & Jusczyk, 1990; Jusczyk & Krumhansl, in prep) and speech (Hirsh-Pasek, Kemler Nelson, Jusczyk, Cassidy, Druss, & Kennedy, 1987; Kemler Nelson, Hirsh-Pasek, Jusczyk, & Cassidy, 1989). Despite certain processing similarities, we expect that the infant system treats the two types of input as different. A direct test of this hypothesis seems not to have been done, however (P. Jusczyk, personal communication). Even without the result from such a study, the theoretical and empirical evidence from animal work, neuropsychology, and evolutionary theory suggests that speech and music are neither subsets of each other nor parts of the same system.

First principles support domain-specific learning

The structure of a domain

When we postulate that young children's cognitive development is directed by domain-specific principles, we find it helpful to use the metaphor

of a skeleton. Were there no skeletons to dictate the shape and contents of the bodies of pertinent knowledge, then the acquired representations would not cohere. Just as the skeletons of different creatures are assembled according to different principles, so are separate, coherent bodies of knowledge. Skeletons need not be evident on the surface of a body; similarly, the underlying axiomlike principles that enable the acquisition of coherent knowledge need never be accessible to conscious description. Most of us could not formally describe the tonal system of our culture, yet we use the principles of the system to guide judgments of, for example, how well a given note "fits" in a musical context (Krumhansl & Keil, 1982).

The skeleton metaphor is less than perfect because it gives the impression that all principles are in place before the body of knowledge defined by them is acquired. This need not be; it is possible, even likely in many cases, that only some subset of a domain's principles serve this function. It is also conceivable that the initial ones are replaced or expanded over the course of learning. Such replacement or revision of principles is especially likely if the learner acquires new or enriched theories, such as those Carey (1985) has described for biology, or if the learner receives domain-relevant instruction. An example of the latter might be the restructuring of knowledge that comes as young musicians expand their representation of rhythm to include both the principles of meter and the principles of rhythmic figure (see Bamberger, 1990). A developing capacity for mapping language onto principles that are not at first stateable or even symbolically represented may also lead to replacement or expansion (Gelman, M. Cohen, & Hartnett, 1989; Karmiloff-Smith, 1986; 1992).

Relevance

In much the same way that the innate learning mechanism in avian species attends to stimuli that are tonally, phonemically, and/or rhythmically relevant to acquiring the species' song, so do the initial principles of a human, cognitive domain mark out the stimuli that are candidates for assimilation to that domain, stimuli that will feed coherent development within that domain. Our ideas for relevance in a domain are quite like those outlined by Sperber and Wilson (1986) for relevance in communication. They write that a phenomenon is relevant to the extent that it possesses features that make it recognizable and easily processed in a cognitive context and to the extent that it adds new knowledge to that already in the context. We might replace the term "cognitive context" with "domain structure" to show the parallel between their ideas and ours. Initial domain structure defines the constraints on the class of relevant inputs and then serves to store, in a coherent fashion, the data that are assimilated. Structural constraints do not force learners to attend to the data; they simply provide guidance as to what are and, hence, what are not the pertinent data. That is, these initial principles are implicit in the processes that govern early behavior and early information processing. Because they lead infants to process data in ways that are consistent with the implicit principles, they account for infants' attention to seemingly surprising things. For example, in the case of number, principles implicit in preverbal counting mechanisms (Gallistel, 1993) can account for infants' attention to stimuli in a number-relevant way (Cooper, 1984; Moore, Benenson, Reznick, Peterson, & Kagan, 1987; Sophian & Adams, 1987; Starkey, Spelke, & Gelman, 1983; Strauss & Curtis, 1984).

Or, we suggest that, in the case of music, perceptual mechanisms sensitive to certain interval relationships between discrete pitches may provide early support for the acquisition of a given tonal system. For example, most of the world's musical systems include an interval that corresponds to the Western perfect fifth (Sloboda, 1985), which is a musically and psychologically important interval in various systems, including those of North India and the West (see Castellano, Bharucha, & Krumhansl, 1984). Its universality suggests that the perfect fifth might be a structure to which the human system is innately sensitive, a conjecture that is supported by the neurophysiological result that the auditory perceptual apparatus of the squirrel monkey is especially sensitive to this relationship (Rose, Brugge, Anderson, & Hind, 1967). Along similar lines, because the Western musical system expresses tonality through harmony rather than through melody (Castellano, Bharucha, & Krumhansl, 1984), certain chords (rather than just intervals) are particularly important and frequently used structures in music. The major triad (in solfège, *do mi sol*) is one such chord and is viewed as something of a prototype of tonal structure (A. Cohen, Thorpe, & Trehub, 1987).

If certain intervals (and perhaps triads) are universally or widely important to music, innate sensitivity to just these sorts of arrangements might be expected. In fact, Western infants are better able to process the perfect fifth interval than an augmented fifth (Trainor, 1993a, b). Similarly, some work has addressed whether Western infants treat the major triad differently from other chords that are nondiatonic or based on an augmented triad. Not all studies have found a statistically significant difference in infants' treatment of sequences based on the major triad versus other triads, but some work provides an indication that the infant system might find the major triad to be an especially coherent structure (e.g., A. Cohen, Thorpe, & Trehub, 1987; Trainor, 1993b; see Trehub, 1987, for a review). For example, one report indicates that infants better remember melodies based on the major triad than they remember those that are not (A. Cohen et al., 1987, Exp. 2). This result suggests that the major triad forms a more stable and coherent context for melodic memorization for infants than do augmented triads (which include accidentals).

The coherence of the major triad could be related to either the simplicity of the ratio (4:5:6) relations among the three frequencies involved in the major triad or to enculturation in the West. The first hypothesis is based on the idea that the frequency relations among the notes in the major triad are simpler than those formed by an augmented triad (12:15:19) and that processing differences are based in the structure of the auditory system (see Trainor & Trehub, 1992). The second hypothesis is that exposure to more tunes based on the major triad than on the augmented triad underlies the processing and memorial differences between the two. As Cohen and her colleagues point out, cross-cultural research is necessary to determine the relative validity of the "simple ratio" and "enculturation" accounts. One such study might involve testing the coherence of the Western major triad for infants (such as those in North India) born into cultures that do not make regular use of tonal triads. If it is the simple ratio formed by the three tones of the major triad that renders it coherent to the infant system, then we would expect it to do so across cultures.

Our point is that cultures whose musical system does not depend on harmony for the expression of tonality may not take advantage of the way the human system reacts to the simple ratios formed by the tones in the major triad, but it does not follow that the system, especially the less-tutored one, does not find such a structure particularly salient and coherent. In sum, we propose that perceptual attention to certain simple frequency ratio relations between tones that form the fifth or the major triad could support the learning of culture-specific tonal hierarchies, simply because (practically) all of the world's tonal systems privilege certain of the uneven intervals in the scale. The perfect fifth is of universal musical importance, and because both infants and nonhuman primates are especially sensitive to this interval, the argument that the human system attends to the fifth, from early on, seems particularly compelling and ripe for cross-cultural, empirical study. Our position relative to the coherence of the major triad is necessarily more speculative but we believe its consonance with our general theoretical viewpoint and its susceptibility to further empirical test make it an attractive one, nonetheless.

Principles need not be in symbolic form

What is the nature of the principles that define a domain and guide attention to relevant information? One characteristic is that principles need not be represented within the system in some symbolic form and, a fortiori, not in a linguistic form. They can be, and most likely are, represented initially within the structure of the information processing mechanisms that assimilate experience and direct action (cf. Karmiloff-Smith, 1992). Marr (1982) covers many cases in which he believes that 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. The case of the "missing fundamental" indicates that the human auditory system imposes harmonic structure on certain arrangements of frequencies; when the higher harmonics of a certain frequency, say 300 Hz, are presented simultaneously, the listener perceives a tone at 300 Hz even though it has not been sounded. From the firing pattern of neurons responding to the harmonics, the auditory system infers the fundamental frequency (e.g., 300 Hz). As far as we know, no one has studied whether this response occurs in infant systems, but its presence early in life would have obvious implications for the argument that certain principles are represented within the structure of processing mechanisms. Along similar lines, the human infant system does not treat the discrete tones of music as single tones that happen to occur at similar times; rather, it seems to infer a structural relationship. Both pitch relationships (such as contour) and relational aspects of temporal structure are encoded rather than individual frequencies of tones and their specific durations (Trehub, 1987).

For the domains in question, assimilation of the environment benefits from available learning processes that are constrained by implicit commitments to deep principles about the world. That is, perceptions and conceptions of entities in the domain are facilitated because the processing systems that are involved are such that they will be especially prone to respond to those kinds of data that are relevant. Again, we are reminded of Sperber and Wilson's (1986) discussion of relevance and their statement that both perceptual mechanisms and perceptual salience are relevance-oriented (p. 152). That is, certain aspects of perceptual mechanisms create a situation in which a specific type of phenomenon can be processed with minimal cognitive effort while allowing for some gain in information about a domain.

Our account of knowledge acquisition within domains, and other accounts in its class, are clearly learning accounts. They differ from more traditional ones in that they postulate innate mechanisms that contribute to the learning of domain-relevant information. The idea is that domain-specific principles guide attention to, and mediate the interpretation of relevant environmental input. True, we posit innate, skeletal principles in some domains, but our definition of a domain is not tied to an assumption of innateness. Whether knowledge represented within a domain can be said to be innate depends on the nature of the evidence. As an illustration, consider tonal and atonal music.

Because there are universal characteristics among the world's various tonal systems, we argue that acquisition of *some* tonal system that shares these features is guided by innate principles. We do not make the same argument for the learning of serial, 12-tone music. Knowledge about this system is certainly acquired (often with some difficulty) by those who receive instruction. In contrast, implicit knowledge of a culture's tonal system is acquired without specific tutoring. Interestingly, nonhierarchical, atonal music systems are not the primary way of organizing musical knowledge in any of the world's cultures (Sloboda, 1985), a fact that adds weight to the argument that certain tonal systems are more "natural" for human systems that are structuring and learning about the aural environment.

More about learning

First principles can impede later learning

The difficulty that most have understanding and learning about 12-tone music is also illustrative of the fact that innate principles do not always facilitate learning. They may provide us with a model of a domain that does not map onto the model needed to learn a certain aspect of the domain. Anyone who remembers struggling with fractions can tell us that some inputs for learning require hard work on the part of both the learner and the teacher. Given that children (or novices) do not always possess the adult (or expert) model for a given domain of understanding, inputs that seem relevant from the adult's perspective need not overlap with those that are relevant from the novice's point of view. This is an unsettling conclusion in that it undermines our faith that we, as possessors of the adult model, can readily create the environments that will best foster its acquisition. As an illustration of the problem, consider how young musicians acquire knowledge of the formal aspects of rhythm (Bamberger, 1990) and how elementary schoolchildren interpret their lessons about fractions (Gelman, 1991).

Bamberger (1990) devotes herself to a discussion of how "minds behind musical ears" might attend to rhythmic features and construct rhythmic entities that are quite different from those attended to and constructed by those who have internalized standard music notation. A child and a teacher may listen to the same short tune but hear very different things. The child, attending to figural aspects of the tune's phrases, hears the first and final phrases as different based on where the phrases occur in the tune, in what context they occur, and with what structural function. The teacher, attending to the pitches and durations of notes in the phrases, hears the first and final phrases as identical. According to Bamberger, educators must look at (rather than through) their own ways of organizing a domain of knowledge in order to make sense of how another person might be organizing the same information.

A related point applies to lessons about fractions. For we now know that young children have a robust tendency to apply their idea that numbers are "what one gets when counting things" to their interpretation of inputs that are meant to foster learning about fractions (Gelman, M. Cohen, & Hartnett, 1989; Gelman, 1991). For example, when 5- to 8-year-old children are asked to order $^{1}/_{56}$ and $^{1}/_{75}$, they choose $^{1}/_{75}$ as the larger number because "75 is more than 56." That is, they answer as if they were asked to compare representations of natural (count) numbers.

These two examples are instances of a more general point. Although principles can foster learning, they can also serve as barriers to learning. If what is to be learned does not share the same structure as available knowledge, then the risk is high that data meant to foster new learning will be assimilated to what is known and, therefore, will be misinterpreted. At this point the learning can become difficult and variable.

But new learning can and does occur. How can this be if the learner's model does not match that of the teacher? We propose that if a law of structural redundancy applies to an account of learning, it provides a potential solution to the fact that, at a given point in time, learners might not share their teacher's interpretations of lessons. If conditions are such that multiple examples of the same equivalence class occur over time, the probability increases that the learner's inclinations and interpretations overlap with at least some of the ubiquitous, relevant inputs. As a result the learner could begin to build local commensurates between what is known and what is to be learned (Gelman, 1991). We turn now to a deeper discussion of this issue.

Characterizing learning in and about environments

Equivalence classes and the law of redundancy. Given that we commit ourselves to the idea that learning is the construction of a model of the world and that it is guided by model-building principles, certain characteristics of the learning process follow. First, the requisite inputs that foster development of the model-building principles and the related model must be described in relational or structured ways. For example, inductions about number depend on opportunities to encounter structured, mathematically relevant inputs, a condition that is not met by low-level sensory bits that are temporally and/or spatially paired. Based on this characterization of relevant inputs for learning, it is no longer obvious that frequent repetitions of the exact same to-be-learned material are either sufficient or necessary for induction. For if learners construct interpretations of what they experience, there is no guarantee that a given stimulus is interpreted the same way at different times. This is because the mental structures that an individual brings to the learning task can change as a function of the given input, the effect of which could be a different future interpretation of the same physical stimulus.

Also, in the constructivist view, environments conducive to knowledge acquisition must share structural relations with the model-building system. This fact mitigates the previous discussion about the possible effects of repeated presentations of the exact same stimulus over time. For the law of frequency can be replaced by a law of redundancy. Now the argument is that learning is facilitated by the presentation of multiple exemplars of inputs that share the same structural description, some of which will overlap with the model-building system. In this case, learning about structure should be fostered by opportunities to encounter different exemplars from the same equivalence class, which is what happens with mathematics lessons in Japanese classrooms (Stigler & Baranes, 1988). Children are encouraged to think of given number facts, for example, 10 + 4, in terms of their mathematical equivalents, such as 5 + 5 + 4, 4 + 10, 2 + 2 + 2 + 2 + 2 + 2 + 2, and so on.

Similarly, learning about tonality may be simplified by the kinds of musical inputs we provide for children, as these inputs are often different nursery songs that strictly adhere to tonal principles, without sharp or flatted (accidental) notes (A. Cohen, et al., 1987; Dowling, 1988). By providing varied instances of inputs that share the same tonal structure, we may aid acquisition of an internal representation of the Western tonal system. Of empirical interest is whether the children's songs of all cultures are structured so as to adhere strictly to the particular tonal system of the culture. Another case that suggests the importance of varied input is that of Anang children learning music. These Nigerian children receive many and varied musical experiences, including singing, dancing, playing instruments, and listening (Gardner, 1983). Perhaps this variability in part accounts for the anthropological finding that all members of Anang society are musically proficient. Just as the physical body requires nutrients from a number of sources in order to develop optimally, so it may be that a variety of exemplars of relevant input may be better for the developing skeleton and body of knowledge.

The foregoing highlights a general reason for our choosing a principle-first account of knowledge acquisition in certain domains. Because first principles guide attention to inputs with a certain structural description, varied opportunities for learning can be attended to. Different cultures can vary in the sample of relevant inputs offered to the young. As long as the samples come from the equivalence class defined by the principles of the domain, cultural variation as to how skeletons are developed can even be the norm. Without the guidance of principles, it is difficult to imagine how structured knowledge could develop from spatially and/or temporally contiguous bits of perceptual information in any culture, let alone in the varied ones of the world. In the absence of such a structure, why should the learner ever relate, for example, one numerically relevant incident with the next, and the next, and so on. In sum, we favor our account over an Associationist one, in part because it explains how the young mind determines what constitutes relevant input and how it binds one relevant encounter with other relevant encounters in a coherent way.

Can cultural differences exist if knowledge structures are innate?

Given the above, cultural differences in count lists or tonal systems do not weaken our argument for innate principles and domain-specific knowledge. Innate knowledge structures do not preclude learning; rather, they encourage it. Our version of nativism in no way precludes learning about the specific ways in which knowledge is organized and used within particular cultures. Quite the contrary, it fits well with the facts.

Cultural inventiveness within biological boundaries. Nature provides learners with a "leg up" in certain cognitive domains; first principles guide attention to the domain-relevant inputs provided by the environment in a culture-specific way. Certainly, the music systems of the world vary widely in structure. Likewise the attitude toward music and its function in the society varies across cultures. Nevertheless, certain universal features, such as an underlying beat structure, the importance of the octave, and a hierarchical tonal system, occur (see Sloboda, 1985). These universals provide us with clues about the contribution of nature to development in the domain of music whereas cultural differences suggest the various ways that human learning can be flexible regardless of innate knowledge. Marler (1991) makes the point for bird song, and we make it for human beings; song development (whether of bird species or human cultures) is a creative process, but inventiveness is governed by certain rules and learning preferences, which are given by nature.

As an illustration of cultural creativity at work within biological guidelines, consider bird song. Despite nature's prescription for relevant input, learning does not lead to the same product even *within* an avian species. For example, dialects among chiffchaffs can be so different that a bird from Germany does not recognize the song of a chiffchaff from Spain (Gallistel, Brown, Carey, Gelman, & Keil, 1991). Dialects of the white-crowned sparrow differ markedly even within the small area surrounding the San Francisco Bay (Marler, 1991). If something as innate as "animal instinct" is not immutable, then it comes as no surprise that human behavior varies as a function of culture and location. Cultural variation is not a death knell for innateness because creativity is guided by innate influences. As Marler (p. 38) puts it, "We cannot begin to understand how a young bird learning to sing interacts with its social and physical environments, and assimilates information from these interactions, without taking full account of innate contributions to the assimilation process." We propose that the story is the same for human infants and children interacting with and assimilating information from social environments that include number-relevant and music-relevant input.

Like the innate learning preferences common to individuals in an avian species, universal principles of counting (e.g., no double counting) or aspects of tonal systems (e.g., uneven intervals between notes in a scale) indicate knowledge that is shared among members of the human species. For both avian and human species, culture influences the form that this knowledge takes, by adding varied amounts and kinds of relevant information to the skeleton provided by the innate organizing principles. The point is that nature does not require that we count with one and only one list or that we use one and only one type of musical scale, just that we do use a list or a scale. Recall Sperber and Wilson's (1986) ideas about relevance; an input is relevant: (1) if it overlaps a bit with "old" information so that it can be recognized and anchored to it; and (2) if it adds some "new" knowledge to the cognitive context. We propose that innate domain-specific principles are just the "old" information that make recognition of relevant inputs possible for the infant system, regardless of cultural specifics. The "new" knowledge to be gained from relevant input is both confirmation of the innate principles and information about the specific way a culture has adapted to the universal features of, for instance, number or music. There are many exemplars in the equivalence class of relevant inputs to a developing domain, and cultures are in part *defined* by the unique inputs they provide to learners.

Symbol systems as evidence. Cross-cultural differences in number and music systems have received a lot of attention, perhaps in part because the symbol systems used differ among cultures. Although we do not take the fact that different languages exist as evidence that certain features of language are not universal, the fact that numbers and music are written differently across cultures leads some to conclude that underlying principles must vary with culture. This interpretation may be particularly seductive in the case of music. What we find is that, although the system that, for example, North Indians use to notate music differs from that used in Western cultures, the two systems have certain underlying commonalities. For example, the mechanics used to indicate pitches differ greatly between the two systems. In North Indian notation, note names that correspond to Western solfège terms are written out whereas Western notation indicates exact frequencies. The North Indian singer may start in the key and octave that is most comfortable, but, for the Western performer, key and octave are given by the notation (Batish & Batish, 1989). Subsequent changes in the pitch height or octave of a tone are indicated to the North Indian performer with a dot above the tone-name if the tone is to be raised or with a dot below the name if the tone should be lowered. Despite these differences in mechanics, however, both notational systems include information about the proper intervals between notes so that this aspect of the piece remains constant even if the key or octave of the piece varies from performer to performer. Obviously, it is the succession of intervals between notes, rather than a specific key or octave, that gives a tune its musical identity. (Transpositions or performances by a tenor vs. a soprano are the same song.) It is this crucial aspect of a piece that both North Indian and Western notational systems specify.

Both North Indian and Western cultures have solved the notational problem in distinct ways, but these solutions are similar in critical ways because the surface features of each system are determined by certain universal aspects of musical structure. The equivalence class of notational schemes that incorporate these underlying structural principles is large and allows for wide cultural variation. Cultural variation may result from the different function or role of music in various societies. In the West, orchestral music is popular. Instruments must be pretuned and exact musical frequencies must be notated in the score if "intonational nightmares" are to be avoided. In traditional North Indian music, music is individualistic and orchestras rare so that it is not necessary to standardize the notation of exact frequencies (Batish & Batish, 1989). Batish and Batish point out that the North Indian notational scheme will have to adapt to changing times, perhaps becoming more Westernized, as the use of ensembles and orchestras to perform film music becomes more popular. The notational system of a culture reflects the role that music plays in that society much like language can reflect the experience of a culture, but because certain aspects of music are universal, so must certain aspects of notational systems, such as attention to pitch intervals, be universal.

Those who learn or develop a symbol system do so within the context of certain specific domains of knowledge, each characterized by its own principles. Any general re-representation ability that develops must honor the constraints of the domain-specific knowledge being re-represented. The meaning of notational symbols is defined by the domain of knowledge that is being re-represented. As an illustration, consider the symbol created when one writes two numbers with one over the other and a line between them. In the numerical domain this symbol refers to a specific numerical entity, for example, 4 over 4, which is mathematically equivalent to other symbol combinations, such as 2 over 2, 1234 over 1234, and 1. In music, the notational configuration of a number over a number with a line between them is created when a time signature is placed on a musical staff. In this case, the notation refers not to a single numerical entity but to the number of beats per measure and to the type of note (e.g., quarter, half, eighth) that defines the beat. As a time signature, 4 over 4 does not share an identity relation with 2 over 2, and, indeed, in the musical domain, time signatures of 1234 over 1234 and 1 do not exist. Not only is 4 over 4 not musically equal to either of them but neither notates a relationship that is meaningful in the domain of music. Of course, in the number domain, the line between numbers is necessary to indicate that they are to be divided. For time signatures, the line is part of the staff, not part of the time signature symbol itself. The point is that to know why the line matters in fractions but not in time signatures, one would need to understand the domain of knowledge to which the symbol refers. Clearly, the meaning of any given notational symbol is domain-specific even when the same physical form (e.g., 4 over 4) of the symbol is used to represent knowledge in various domains. Although the re-representational ability is general, the meaning of any given notational system or symbol can be defined only with respect to the principles of the domain of knowledge that it re-represents.

Innate and universal constraints within a domain will necessarily yield culturally varied notational systems that, nevertheless, pay attention to the same sorts of things. With notation we have a parallel to the situation with counting and musical systems themselves; musical systems or counting behavior must be informed by and adhere to underlying principles, but there are many ways to do this. Variations across cultures simply reveal some of these ways. Our point is that cultural differences need not indicate that some aspects of human knowledge are not universal, for structures that vary on the surface are often built on the same type of foundation.[2]

Notes

1. Marler refers to these features as "syntactic" even though they have more in common with features of music than with features of linguistic syntax.
2. Trehub and Trainor's (1993) chapter on infants' processing of musical patterns appeared after this chapter went to press. Readers will find data and discussion that are relevant to the position we have developed for music.

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15 Cognitive constraints on cultural representations: Natural ontologies and religious ideas

Pascal Boyer

The point of a cognitive approach to cultural representations is to put forward a series of causal hypotheses in order to account for certain features of cultural phenomena. Central to such an inquiry is the notion of *cognitive constraints*; given the general properties of human minds, certain types of representations are more likely than others to be acquired and transmitted, thereby constituting those stable sets of representations that anthropologists call "cultures." To many anthropologists, cultural phenomena seem to lie outside the scope of cognitive constraints, due to three types of reasons: their ontological status, their variability, and their transmission. Cultural anthropology generally focuses on abstract systems of "symbols," "codes," or "meanings," the properties of which are supposed to be independent of the way they are represented in human minds. Second, cultural representations are considered as intrinsically variable; as a consequence, it seems difficult to appeal to universal properties of human minds in their description or explanation. Finally, the content and organization of cultural representations, in competent members of a culture, seem to be entirely constrained by what subjects were taught through social interaction. Against these assumptions, I will take as a starting point the following principles:

1. Cultural systems can and must be studied as sets of mental representations acquired and stored by human minds, because acquisition and memorization processes impose strong constraints on the contents and organization of cultural representations.

2. Their undeniable variability should not lead us to ignore important recurrent features, which deserve an explanation.

3. Finally, the argument that all cultural material is acquired through social interaction is much too vague. It may well be the case that some important aspects of cultural representations are precisely not acquired through socialization.