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EMBODIED CONCEPT LEARNING

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HOW CONCEPTS ARE LEARNED

p0010

We address the question “How do people learn new concepts?” from the perspective of Unified Cognitive Science. By Unified Cognitive Science, we simply mean the practice of taking seriously all relevant findings from the diverse sciences of the mind, and here we are focusing on the question of concept learning. The particular perspective on concept learning advocated here grows out of the Neural Theory of Language project (www.icsi.Berkeley.edu/NTL), but is compatible with most cross-disciplinary work in the field.

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Leaving aside for now Fodor’s (1998) argument that concepts cannot be learned (which turns on disputable definitions of *learn* and *concept*), concept learning poses an ancient and profound scientific question. If we exclude divine intervention, then there are only two possible sources for our mental abilities: genetics and experience. There is obviously something about our genetic endowment that enables people, but not other animals, to become fluent language users and possessors of human conceptual systems. As nothing can enter our minds without intervention of our senses, which are themselves in large part the product of genetics, nature must provide the semantic basis for all the concepts that we acquire. So, in some sense, people really cannot learn any concepts that go beyond the combinatorial possibilities afforded by genetics.

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At the same time, the conceptual systems of individual humans are profoundly marked by their experience—from maternal vocalization while still in the womb (Moon et al., 1993) to experience with culture-specific artifacts like



baseball, chairs, or bartering practices. Evidence for relativistic effects of language on conceptual categories (Majid et al., 2004; Boroditsky, in press) shows how conceptual systems are shaped by linguistic and other cultural experience. The scientific question confronting the field is how conceptual systems, which are so profoundly constrained by genetics, can at the same time be shaped by experience such that they display the great breadth of cultural diversity that they do.

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A coherent and plausible picture of human concept learning is arising from combining biological, behavioral, computational, and linguistic insights. This account is similar in form to the solution to another biological question—a question for which the answer is now understood in great detail. That is the question of immunology. Animal immune systems are remarkably good at generating antibodies to combat novel antigens that invade the body. The raging question used to be whether this is a process where the killer antibody is selected from a fixed innate repertoire or whether the system somehow manufactures a custom antibody, instructed by the intruder. The full answer is beyond the scope of this chapter (and our knowledge) but the basic idea is clear. The immune system works because of a large number of primitive molecules that, in combination, can cover an astronomical number of possible antigens. These immunological primitives also evolve but not fast enough to attack a new intruder. Gerald Edelman, who won the 1972 Nobel Prize for his research on the selection/instruction problem in immunology, has worked for decades to show how the same combinatorial principles can help explain the mind (Edelman, 1987).

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A “primitives plus composition” account of conceptual structure is appealing but requires further specification. We need an account of how primitive concepts arise, and an account of how the processes of conceptual composition work to generate new concepts. Details are emerging from a unified approach to cognitive science, and the story goes something like as follows. There is indeed an internal foundation for our concepts and it is we, as part of our animal heritage, who have a wide range of perceptual, motor, emotional, and social capabilities all expressed in our neural circuitry. This neural circuitry forms the basis for primitive concepts, which are in turn grounded in these neural structures. Furthermore, like our primate cousins, we have considerable competence at combining existing concepts to achieve desired goals, through binding, conjunction, and analogy, among other mechanisms.

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In what follows, we will be using facts about language in our discussion of concepts and thought. Language is a particularly clear conduit to mental organization. Words express a speaker’s concepts and evoke them in the listener. Much of conscious internal thought appears to be self-talk and, as we will discuss, there are many well-established empirical findings demonstrating how words are linked to concepts. This embodied view of language is hardly novel. Pinker and Jackendoff (2005) present a wide range of current evidence for the evolutionary continuity of language and thought. And within traditional



philosophy, the American Pragmatists¹ stressed the continuity of all human activity and our evolutionary continuity. Thus, for our present purposes, a *concept* is the meaning of a word or phrase. This includes both basic, embodied words like *red* and *grasp* as well as abstract and technical words like *goal* and *continuity*. We will not address the possibility that there are concepts that cannot be described in words.

p0070 We will first provide an outline of the modern view of concepts as embodied, then outline how concrete concepts are learned, and discuss some known mechanisms for constructing new concepts from previously known ones.

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EVIDENCE FOR EMBODIED CONCEPTS

p0080 Using concepts—accessing their features, imagining them, recalling them, and processing language about them—makes extensive use of their perceptual, motor, social, and affective substrates. The picture that has emerged from the broad range of convergent evidence surveyed below shows that when people use concepts, they perform mental simulations—internal enactments—of their embodied content.

p0090 Let us start with an example. Can you say how many windows there are in your current living quarters? Almost everyone simulates a walk-through to count them. Or consider a novel question—could you make a jack-o-lantern out of a grapefruit? To access the concept of a grapefruit—to reflect on its actual or hypothetical properties or to compare or combine it with other entities—you make use of detailed, encyclopedic and modality-specific knowledge. Subjectively, accessing this knowledge takes the form of sensory and motor experiences associated with the concept; reflecting on the carvability of a grapefruit involves creating internal motor and sensory experiences of carving a jack-o-lantern out of a grapefruit. Any time we use concepts, whether in performing categorization tasks, processing language about concepts, or reflecting on their features, we use mental simulation—the internal creation or recreation of perceptual, motor, and affective experiences. And we can simulate these experiences from different perspectives—it is quite different to imagine pushing, being pushed, or observing a third party pushing.

p0100 The notion that mental access to concepts is based on the internal creation of embodied experiences is supported by recent brain research, which shows that motor and pre-motor cortex areas associated with specific body parts (i.e., the hand,

¹From The Internet Encyclopedia of Philosophy: “The basis of Dewey’s discussion in the *Logic* is the continuity of intelligent inquiry with the adaptive responses of pre-human organisms to their environments in circumstances that check efficient activity in the fulfillment of organic needs. What is distinctive about intelligent inquiry is that it is facilitated by the use of language, which allows, by its symbolic meanings and implicatory relationships, the hypothetical rehearsal of adaptive behaviors before their employment under actual, prevailing conditions for the purpose of resolving problematic situations.”



leg, and mouth) become active in response to motor language referring to those body parts. Using behavioral and neurophysiological methods, Pulvermüller et al. (2001) and Hauk et al. (2004) found that verbs associated with different effectors activate appropriate regions of motor cortex. In particular, Pulvermüller and colleagues had subjects perform a lexical decision task—they decided as quickly as possible whether a letter string was a word of their language, with verbs referring to actions involving the mouth (e.g., *chew*), leg (e.g., *kick*), or hand (e.g., *grab*). They found that the motor cortex areas responsible for mouth, leg, and hand motion exhibited more activation, respectively, when people were processing mouth, leg, and hand words. This result has been corroborated through transcranial magnetic stimulation work (Buccino et al., 2005). Tettamanti et al. (2005) have also shown through imaging that passive listening to sentences describing mouth versus leg versus hand motions activates corresponding parts of pre-motor cortex (as well as other areas).

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Behavioral studies also offer convergent evidence for the automatic and unconscious use of perceptual and motor systems during language processing. Work on spatial language (Richardson et al., 2003; Bergen et al., 2007) has found that listening to sentences with visual semantic components can result in selective interference with visual processing. While processing sentences that encode upward motion, like *The ant climbed*, subjects take longer to perform a visual categorization task in the upper part of their visual field (deciding whether a shape is a circle or a square). The converse is also true—downward-motion sentences like *The ant fell* interferes with shape categorization in the lower half of the visual field. These results suggest that understanding spatial language evokes visual simulation that interferes with visual perception.

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A second behavioral method (Glenberg & Kaschak, 2002) tests the extent to which motor representations are activated during language understanding. When subjects hear or read a sentence that describes someone performing a physical action, and are then asked to perform a physical action themselves, such as moving their hand away from or toward their body in response to a sentence, it takes them longer to perform the action if it is incompatible with the motor action described in the sentence. For example, if the sentence is *Andy gave you the pizza*, subjects take longer to push a button requiring them to move their hand away from their body than one requiring them to move their hand toward their body, and the reverse is true for sentences indicating motion away from the subject, like *You gave the pizza to Andy*. This interference between understanding language about action and performing a real action with our bodies suggests that, while processing language, we use neural structures dedicated to motor control.

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A third method, used by Stanfield and Zwaan (2001) and Zwaan et al. (2002), investigates the nature of visual object representations during language understanding. Zwaan and colleagues have shown that the implied orientations of objects in sentences (like *The man hammered the nail into the floor* vs. *The man hammered the nail into the wall*) affect how long it takes subjects to decide whether an image of an object (such as a nail) was mentioned in the sentence.

When the image of an object is seen in the same orientation as it was implied to have in the sentence (e.g., when the nail was described as having been hammered into the floor and was depicted as pointing downward), it takes subjects less time to perform the task than when it was in a different orientation (e.g., horizontal). The same result is found when subjects are just asked to name the object depicted. Zwaan and colleagues also found that when sentences imply that an object would have different shapes (e.g., an eagle in flight vs. an eagle at rest), subjects once again responded more quickly to images of that object that were coherent with the sentence—images of that objects that have the same shape as they would have as described in the sentence.

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A final method investigates whether sentences take longer to process when the scenes they describe take longer to mentally scan. Matlock (2004) demonstrates that the time subjects take to understand fictive motion sentences (sentences like *The road runs through the desert* or *The fence climbs up to the house*) is influenced by how quickly one could move along the described paths. For example, a sentence like *The path followed the creek* is processed faster when it follows a paragraph describing an athletic young man who jogs along the path than when it follows one describing an old man who has difficulty walking all the way down the path. Similarly, characteristics of the path itself like its distance or difficulty to navigate influence processing time in the same direction—the longer it would take the mover to travel the path, the longer it takes subjects to process the fictive motion sentence. This work once again implies that processing language makes use of a dynamic process of mental simulation.

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These convergent results suggest a major role for embodied perceptual and motor experiences in language understanding. Language understanders automatically mentally imagine or simulate the scenarios described by language. The mental simulations they perform can include motor detail at least to the level of the particular effector that would be used to perform the described actions, and perceptual information about the trajectory of motion (toward or away from the understander; up or down) as well as the shape and orientation of described objects and paths. The neural imaging studies cited above suggest that these simulations involve some of the very brain mechanisms responsible for perceiving the same percepts or performing the same actions.

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Mental simulation has an equally important role in other higher cognitive functions like memory and imagery. Behavioral evidence shows that recalling motor experiences recruits cognitive mechanisms responsible for performing the same motor actions (Barsalou, 1999). Several recent neural imaging studies show that this cognitive overlap mirrors a neural overlap; recalling motor experiences makes use of motor-control-specific neurocognitive structures (Wheeler et al., 2000; Nyberg et al., 2001). Similarly to recall, the performance of mental imagery involving motor control or visual or auditory perception yields activation of appropriate motor or perceptual brain areas (Porro et al., 1996; Lotze et al., 1999; Kosslyn et al., 2001; Ehrsson et al., 2003). It thus seems that recalling, imagining, or understanding language about actions and percepts recruit brain structures

responsible for performing the actions or perceiving the percepts that appear in the mind's eye.

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Even purely conceptual tasks involve the activation of modality-specific knowledge. For instance, in performing a property verification task (e.g., *Is mane a property of horse?*), subjects make use of mental simulation. This is demonstrated through longer times to correctly identify more perceptually difficult (e.g., smaller or physically peripheral) properties (Solomon & Barsalou, 2001, 2004). Using the same property verification task, Pecher and colleagues (2003, 2004) showed that verifying properties for the same concept from different sensory modalities (e.g., Apple-Green and Apple-Shiny) entailed a cost in processing time, relative to verifying properties from the same modality (e.g., Apple-Tart and Apple-Shiny). Both of these sets of findings imply that subjects performing mundane property verification are accessing modal mental simulations.

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Other conceptual tasks also require mental simulation. One of the most important of these for conceptual processes is the use of covert or inner speech. At more or less frequent intervals, most people report the subjective experience of hearing a voice in their mind's ear, and also of feeling themselves articulating speech, especially when they are performing or preparing for cognitively difficult tasks. Talking to oneself internally, even without producing any speech or speech gestures, is itself demonstrably a sort of mental simulation. Empirical measures confirm that the motor and auditory systems are activated during inner speech. For example, covert speech results in brain activation whose lateral localization correlates with that of overt, actual speech (Baciu et al., 1999). In addition, covert speech, which results in no visible facial movement, nevertheless yields significantly greater electrical activity in the oral articulators than non-linguistic tasks like visualization (Livesay et al., 1996). And finally, activation of brain areas responsible for actual language production can be shown to be critical for covert speech through evidence that suppressing activity in these areas through transcranial magnetic stimulation results in decreased performance in both overt and covert speech tasks (Aziz-Zadeh et al., 2005). Inner speech is a sort of mental simulation of a particularly interesting variety, as it can itself drive mental simulation of a second sort. Suppose that one is taking care to correctly attach jumper cables to start a car with a dead battery. If one says to oneself *First attach one red clip to the positive post of the dead battery, then the other red clip to the positive post of the good one*, then this internally generated language, like language that a hearer might perceive, drives an enactment of the described events. This simulated experience thus facilitates simultaneous or future performance of the same task.

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All these lines of research point to a common conclusion. Conceptual processes make use of the internal execution of imagery, qualitatively similar to the past experiences it is created or recreated from. As such, using concepts is qualitatively similar in some ways to experiencing the real-world scenarios they are built from. It is important to note that motor and perceptual experiences hold a privileged position in the study of mental simulation only because their basic

mechanisms and neural substrates are relatively well understood. Other dimensions of experience are also relevant to simulation: anything that is experienced, including affect, social interactions, subjective judgments, and other imagined scenarios can be recruited to form part of a simulation. For example, recent work suggests that processing language about scenarios in which a protagonist would be likely to experience a particular emotion yields the internal recreation of similar affective experience on the part of the understander (Glenberg et al., 2005).

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There are obviously limits to the extent to which previous experience can define simulation. If conceptual knowledge, as argued here, involves the activation of motor and perceptual (and other) representations of past experiences, then how can counterfactual or previously unexperienced meanings be understood? After all, one of the “design features” of human language is the possibility of describing things that do not exist (Hockett, 1960), for example, “the Easter Bunny” or “the current King of France.” Moreover, because language is so important in helping children (and adults) learn about the world, it cannot be the case that linguistic meaning simply associatively reflects past experiences—if this were the case, then we could never learn anything new through language. However, a mental simulation-based account of meaning does not imply a purely behaviorist or empiricist perspective. In fact, as Kosslyn and colleagues (2001) argue, there is good reason to believe that “mental images need not result simply from the recall of previously perceived objects or events; they can also be created by combining and modifying stored perceptual information in novel ways” (p. 635). Mental simulation involves the active construction by the conceiver of novel perceptual, motor, and affective experiences, on the basis of previous percepts, actions, and feelings. Although it is constrained and informed by these experiences, compositional and other creative capacities allow departures from them.

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One class of these is counterfactual or hypothetical situations, like those described through negation or conditionals (Fauconnier, 1985; Dancygier & Sweetser, 2005). For instance, an utterance like *If you hadn't painted your wall red, you wouldn't have gotten grounded* describes two scenes, neither of which actually happened (the non-painting of the wall and the non-grounding). There is evidence that suggests that language like this, and the corresponding reasoning, evokes simulations of the counterfactual or hypothetical scenes, though more transiently than factually presented content (Kaup & Zwaan, 2003).

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There is also a significant literature on the computational modeling of actions and how such models can be learned and used. The most relevant work employs models of action that are themselves executable; that is, the models specify in detail how the action (say grasping) is carried out. Our work on the Neural Theory of Language uses a Petri-net based formalism called X-schemas (Bailey, 1997; Narayanan, 1999). The same X-schema can be used for carrying out an action, planning it, recognizing the action, or understanding language about it. The X-schema computational mechanism antedates the discovery of mirror neurons (Rizzolatti & Craighero, 2004) but obviously fits those data. The same

formalism has proved its utility in simulation-based programs for understanding stories such as those found in newspapers (Narayanan, 1999).

p0230 As other authors have presented more detailed accounts of how neurally embodied concepts exhibit the behaviors traditionally ascribed to concepts, such as compositionality, internal structure, and so on (Barsalou, 1999; Gallese & Lakoff, 2005), we will forgo further discussion of those issues here. Instead, we will focus in the next section on how embodied concepts are learned.

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LEARNING BASIC WORDS/CONCEPTS

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From birth, children exhibit imitation and other social skills (Meltzoff & Prinz, 2002). They develop sophisticated methods of communication and joint attention well before they produce any language (Hoff, 2001). So we know that children have a rich set of conceptual and communication skills before they produce any language (Mandler, 1992, 2004).

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Children learning about the world (and how to communicate about it) start first with concepts and words that are grounded in their direct perceptual and motor experiences. First words vary significantly across individuals, but most English-speaking children's first words (Figure 16.1) consist predominantly of concrete nouns, like *truck* and *ball* and social-interactional words, like *up* and *more* (Bloom, 2000; Tomasello, 2000). It is relatively obvious that concrete nouns are grounded in direct experience, but importantly, social-interactional words are equally bound to embodied experience. A child who utters *up!* is not soliloquizing on the existence of "upness" in the universe—he is using the word to label (often to bring about) a particular type of experience, where he

	cow								
apple	ball								yes
juice	bead		girl				down		no more
bottle	truck		baby	woof	yum	go	up	this	more
spoon	hammer	shoe	daddy	moo	whee	get	out	there	bye
banana	box	eye	mommy	choo-choo	uhoh	sit	in	here	hi
cookie	horse	door	boy	boom	oh	open	on	that	no

food toys misc. people sound emotion action prep. demon. social

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FIGURE 16.1 The words learned by most 2 year olds in a play school (Bloom, 1993).

is lifted. Often children also acquire concrete verbs like *get* and *sit*. It is only once they are far along in their development of these words that they begin to develop language for abstract, distant, or general concepts (Johnson, 1999). Conceptual development progresses in the same way, with concrete and directly experienced concepts leading the way for greater complexity. In addition to concepts that directly label their experience, children have pre-linguistic organizing schemas, such as support, containment, and source-path-goal (Mandler, 1992, 1994).

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If all children acquired words and concepts identically, with concrete words and concepts being learned first—object before actions—and then abstract ones coming an afterward, then concept development could plausibly be accounted for as the progressive maturation of innate concepts. However, across languages and cultures, systematic differences in the character of children's experience, including linguistic differences and others, yield systematic variation in the course of word and concept acquisition. For instance, Korean and Chinese are languages in which verbal arguments can be omitted if they are obvious from context. Thus, if it is clear to both interlocutors that they are talking about what the doll is doing to the cake, the speaker would not have to say the equivalent of *The doll is throwing the cake* or even *She is throwing it*—it would suffice to say the equivalent of *Is throwing*. As a result, children growing up learning Korean and Chinese, and other languages like them, hear fewer nouns than their English-learning counterparts, and their order of word acquisition differs accordingly; significantly more of their early words are concretely grounded verbs (Choi, 2000). There is no universal order of word or concept acquisition—the only one is that children start by labeling concepts that are directly accessible to them through experience, whatever their experience happens to be.

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The account we present here, then, is quite straightforward. Children learn their early words and concepts on the basis of perception, action, and other aspects of their embodied experience. Early words, and their conceptual meanings, are schematic representations of experiences, which abstract away from certain details, but still remain tightly bound to the modality-specific experiences they are based on. Using a concept thus involves reactivating a subset of those neural structures that underlay the experience in the first place. Language learning is closely integrated with conceptual learning, as a learner comes to associatively pair two aspects of experience—the perceptuo-motor schemas responsible for the perception and articulation of a particular piece of language, together with the schemas corresponding to its meaning. Moreover, language directs a learner to attend to certain aspects of his perceptual and motor experiences to make categorical linguistic distinctions (McDonough et al., 2003).

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A strong test of this account is to build a computational model that realizes its claims, and see if it exhibits the right behavior. Bailey (1997) did just this when he built a program that was meant to learn the meanings of a subset of hand action words. To do this, the model needed to capture the full range of the conceptual space of potential hand actions, as described in any of the world's

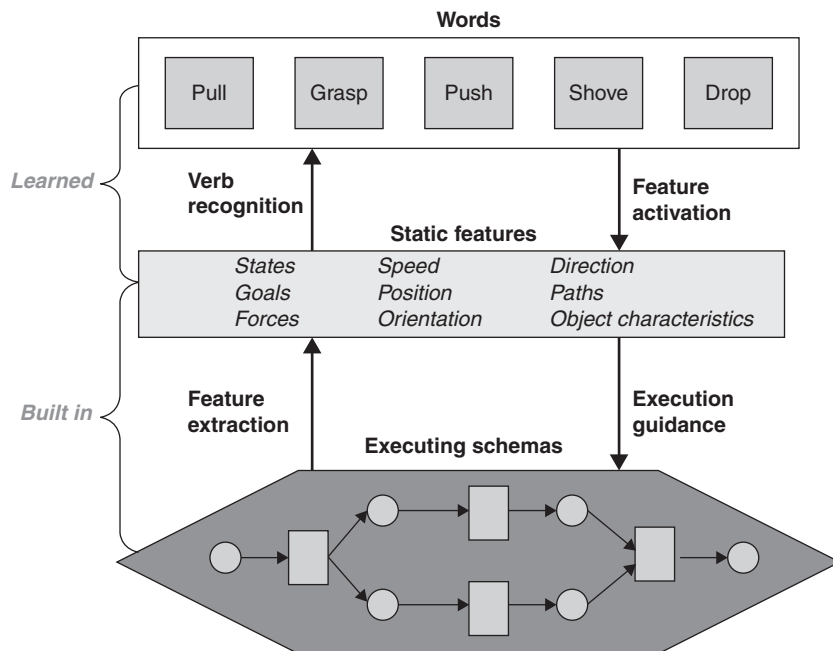
languages. Building in too many assumptions would preclude learning some languages, whereas leaving everything unspecified would give the program no chance of learning at all. Bailey's (1998) solution was to base his solution on the body and on neural control networks. The idea is that all people share globally similar neural circuitry and bodies and thus exhibit the same semantic potential.

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But there seems to be a complexity barrier. How could the meaning of an action word be the activity of a vast distributed network of neurons? The key to solving this in Bailey's (1998) model, and also in the brain, is *parameterization*. A motor action such as grasping involves many coordinated neural firings, muscle contractions, and so on, but we have no awareness of these details. What we can be aware of (and talk about) are certain parameters of the action—force, direction, effector, posture, repetition, and so on. The crucial hypothesis is that languages only label those action properties of which we can be aware. That is, there is a fixed set of embodied features that determine the semantic space for any set of concepts, such as motor actions.

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Figure 16.2 presents an overview of Bailey's model for learning words that describe one-hand actions. The first thing to notice is that there is an intermediate set of features, shown as a large rectangle in the middle of the figure. These are the parameters just discussed—those aspects of actions that we can consciously know about can be described by a relatively small number of features. People do not have direct access to the elaborate neural networks that coordinate



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FIGURE 16.2 Overview of Bailey's model for learning action verbs.

our actions and neither does the model. This parameterization of action is one key to the success of the program.

p0310 A second critical feature of the model is the schematic representation of actions, called executing schemas (X-schemas) as shown at the bottom of Figure 16.2. In addition to parameters like force, actions are characterized by control features. For example, some actions are repetitive, some conditional, and so on. Depicted in Figure 16.2 is a generic control diagram showing an action followed by a test that causes branching to one of two alternatives, either of which leads to the final state. This kind of abstract action schema is common in the motor control literature and has also been used effectively in various computational models. The X-schema computational formalism for actions has considerable independent interest (Narayanan, 1997). The crucial point here is that control of action can also be parameterized and thus be made available to language learning. Even with these representational insights, the computational problems involved in embodied language learning are significant. The key to Bailey's success was approximating best-fit neural computation with Bayesian MDL (minimum description length) learning algorithms (Bailey, 1997).

p0320 In Figure 16.2 we note that the arrows are bi-directional. The system not only learns to label actions with words but will also carry out requests expressed using the words that it has learned. The upward arrows on the left describe the labeling pathway—features are extracted from executing schemas (bottom right arrow) and then these features are used to decide which verb is the most appropriate label for the action. The corresponding two-step path from word to parameters to action is depicted on the right of the figure.

p0330 Bailey's program learned the appropriate words for hand actions for a range of different languages, including Farsi and Spanish. A somewhat similar program by Regier (1996) learned spatial relation terms across languages that conceptualize these quite differently, including English, Russian, and Mixtec, a language that bases a large part of its spatial language on body parts. In principle, and as demonstrated by models like these, in practice as well, there seems to be no barrier against explaining in detail how children could learn those words of their language whose semantics is directly embodied. Projecting beyond existing models, these should also include words based on emotional and social cognition as well as perception, action, and goal seeking. Basic words and their concepts label instances and combinations of core neural capabilities. In the next section, we suggest how these mechanisms are extended in the learning and use of words for abstract and technical concepts.

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LEARNING AND USING ABSTRACT AND TECHNICAL WORDS AND CONCEPTS

p0340 We have argued that language about directly experienced aspects of the world and the related concepts derive from generalization over concrete, embodied

experiences. Abstract language and concepts—those with a less direct basis in experience—are built up from these conceptual primitives, by combining them using a modest set of productive mechanisms.

p0350 Existing concepts are used to produce novel ones through composition mechanisms like the following: conjunction (a narwhal is easily learned to be like a beluga with a long unicorn-like tusk); modification (a llama is like a camel without a hump); abstraction (a vehicle is anything that can be used for transportation); and mapping (ideas are like objects) among others. These productive mechanisms can function through direct perceptual or motor experience (e.g., seeing an image of a narwhal). But language can also indirectly ground conceptual learning. As discussed earlier, language drives perceptual, motor and affective simulation. This simulation itself constitutes experience that can form the basis for new concepts. Thus, one's only experience with flamingos being used as croquet mallets might be through reading about it (Carroll, 1865), but that still might be part of one's conceptual knowledge about flamingos. The mental experience driven by language, and reproduced using the relevant neural circuits, is a sufficient basis for conceptual reorganization.

p0360 In fact, because of the brain's massive connectivity and spreading activation, concepts are never learned or activated in isolation as each of us boasts richly interrelated concepts. We are also continuously composing or "blending" concepts. For example, quite different hues are suggested by "red hair", "red pencil", "red light", and so on. We easily understand and image novel combinations like "mauve marzipan narwhale." Fauconnier and Turner (2002) are particularly interested in blends that combine different domains through mapping to a common space like "trashcan basketball." They suggest that the human ability for complex conceptual integration was the key evolutionary advance that gave rise to language and thought.

p0370 The best studied of mechanisms for grounding abstract concepts is through mappings to them from concrete source domains. Abstract conceptual domains have long been known to be talked about in terms of concrete source domains, through linguistic metaphor. For instance, English speakers (and speakers of many other related and unrelated languages) talk about ideas in terms of objects and knowledge in terms of object manipulation. For instance, *I'm running out of ideas*, *I'm in the market for some new ideas*, *Now that we've deconstructed the proposal, let's see if we can reassemble it*, and *I'm having trouble grasping the gist of the sermon*. Close analysis of texts reveals that for most abstract domains, non-expert language users exploit very little, if any, non-metaphorical language. The domain of ideas is a case in point. Ideas can be possessed, acquired, shared, chewed on, swallowed, recast, and worn out, among many other metaphorical construals.

p0380 A large body of research spanning the past 30 years provides convergent evidence that abstract conceptual domains are not only talked about in terms of these concrete ones but are also actually thought about in terms of them as well. Early work in the Cognitive Linguistics framework (Lakoff & Johnson, 1980; Lakoff, 1993) provides three main types of evidence that metaphor is not just describing-as

but conceptualizing-as. First, there metaphorical language is systematic—when ideas are described as objects, considering the idea is always manipulating the object; the considerer is always the manipulator, and the idea is always the object (and never the reverse). Second, this metaphorical language is productive. It is not just due to a set of conventionalized metaphorical meanings associated with particular words. Instead, concrete language is regularly used in novel, metaphorical ways, like the word *disintegrated* in *The new human stem cell research disintegrated under the light of scrutiny*. Third, not just language but also reasoning transfers from a concrete conceptual domain to an abstract one through a metaphor. So if *this theory is hard to get a grip on*, then we infer that this is due to a property of the theory itself—it is slippery or bulky—or to a property of the understander—they do not have sufficient mental skills to get their head around it. More recently, an important fourth type of evidence has appeared, behavioral evidence using tools from cognitive psychology, showing that language users activate concrete source domains when thinking about abstract target domains (Gibbs et al., 1997; Boroditsky, 2000, 2001; Tseng et al., 2005).

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How do learners come to understand an abstract domain in terms of a concrete source domain? In the simplest cases, the two domains are aligned in experience and can thus become associated (Lakoff & Johnson, 1980; Grady, 1997). For instance, quantity is a relatively abstract domain, especially when applied to concepts like power, love, and social capital. But in early childhood experiences, as throughout life, quantity of physical entities varies systematically with concrete, perceptible correlates. Perhaps most pervasive of these is relative height. In general, the more liquid in a container, the higher the level of the liquid; the more objects in a pile, the higher the pile. The systematic correlation between a concrete, perceptible cue (physical height) and more abstract and subjective one (quantity) leads the learner to scaffold the conceptual and linguistic structure on top of the former. As the learner subsequently develops, the two domains are pulled apart—adults know that abstract quantity does not always correlate with physical height. But the conceptual and linguistic links between the two domains persist, as shown in the four types of evidence described earlier.

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The case of conceptual metaphor shows not only how abstract concepts can be built up on the basis of concrete ones, but also how existing conceptual structures can be productively combined. It is clear that the metaphorical grounding account sketched out above is insufficient to completely deal with some cases, like *Theories are buildings* (*Modularity is a foundation of the theory of generative grammar; These observations buttress the theory of natural selection, Under the weight of conflicting evidence, the Newtonian physics came crashing down, etc.*). There is no experiential correlation between the creation and structure of buildings on the one hand and the invention and organization of theories on the other. But Grady (1997) has shown that the actual mappings by which theories are described and understood as buildings are partial—only certain aspects of buildings are mapped onto theories. These include the physical structure of buildings (foundation, support, and buttresses), and their persistent erectness but not

plumbing. The metaphor *Theories are buildings* is thus best seen as instantiating a combination of two primary metaphors—*Persistent functioning is remaining erect*, and *Abstract organization is physical structure*. Each of these has a clear basis in experience. Many physical objects, like buildings, trees, chairs, and so on, function persistently only while erect. Many objects with complex physical structure also have associated organization—the legs are not only at the bottom of a table but also serve to the function of support. Put together through composition, these two primary metaphors produce a mapping whereby *Persistently functioning entities with abstract organization are erect objects with physical structure*. Buildings happen to be a good example of concrete objects with physical structure that saliently remain erect, and theories happen to be a good example of abstract entities with organization that persists.

p0410 Concrete concepts are learned through schematization over direct experiences and abstract concepts are indirectly grounded through co-experience with concrete ones, or through compositional mechanisms that produce them on the basis of previously grounded ones.

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CONCLUSIONS

p0420 We have provided an outline of how people learn and use new concepts. The account provides a plausible theory that is supported by a broad range of linguistic, computational, behavioral, and brain imaging data. It goes something like as follows:

- o0010 1. Our core concepts are based on the neural embodiment of all our sensory, motor, planning, emotional, and social abilities, most of which we share with other primates. This yields a huge, but not unbounded, collection of primitives.
- o0020 2. We can only be aware of or talk about a limited range of parameters over these abilities and human languages are based on these parameterizations, plus composition. Composition can give rise to additional abilities and parameters.
- o0030 3. The meanings of all new words and concepts are formed by compositions of previously known concepts. We use a wide range of compositional operations including conjunction, causal links, abstraction, analogy, and metaphor.
- o0040 4. Domain relations, particularly conceptual metaphors, are the central compositional operations that allow us to learn technical and other abstract concepts.
- o0050 5. We understand language by mapping it to our accumulated experience and imagining (simulating) the consequences.

p0480 We could end this chapter here, but there is a related a priori contention that we can address with the same basic line of reasoning—the postulated innateness



of grammar. The logical argument from the “poverty of the stimulus” (Chomsky, 1980) proposes that children do not get a rich enough training to enable them to learn the grammar of their native language(s). The reasoning summarized above provides part of the answer to the grammar learning problem, a solution one might call the “opulence of the substrate.” This alternative states that children come to language learning with a very rich collection of conceptual primitives, rules for composing them, and breadth of embodied experiences. None of these is specifically tailored to language.

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The only additional insight required is that grammar is itself constituted of mappings from linguistic form to meaning. A rule of grammar is what linguists call a *construction*, a form–meaning pair. We can combine the idea of linguistic constructions with the notion of embodied meaning outlined above and define Embodied Construction Grammar or ECG (Bergen & Chang, 2005). In ECG, a word like “into” maps to its conceptual meaning—a source–path–goal schema with its goal role bound to the interior role of a container schema. Larger constructions at the phrasal level would map a phrase like “into the house” into a conceptualization where the house was assigned as the conceptual container.

p0500

Given that language is embodied and that grammar maps from sound to experience, the child’s problem in learning grammar is not overwhelming. They learn basic words as labels for their experience, as pointed out in the section on Learning basic words/concepts. The key insight for learning compositional rules of grammar is that the job of a grammar rule is to specify conceptual composition. A child who already understands a scene conceptually and hears a sentence about it only needs to hypothesize what about the linguistic form licenses the known conceptual composition. Of course, these early hypotheses about grammar rules are sometimes wrong, and the usual learning processes of testing, refinement, and abstraction are also involved. This is a short version of a fairly long and complex story, but a full and computationally tested account is available in theses by Chang and Mok (2006). Some additional descriptions of ECG and its applications can be found in Chang et al. (2002) and Bergen and Chang (2005).

p0510

An account of concept learning based on cognitive and evolutionary continuity triggers an obvious question: what is unique about the human mind that enables us to become fluent language users and conceptual thinkers? This is a subject of considerable current research, most notably in Michael Tomasello’s group in Leipzig. There is unlikely to be a single feature that explains all unique human mental attributes, but Tomasello has identified one feature that is clearly important—the ability to understand other minds. From our perspective, mind reading appears to be a special case of a more general capability for mental simulation. As we have seen, there is converging evidence that people understand language and other behaviors at least in part by simulation (or imagination). This ability to think about situations not bound to the here and now (*displacement*) is also obviously necessary for evaluating alternatives, for planning, and for understanding other minds.

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More speculatively, there is a plausible story about how a discrete evolutionary change could have given early hominids a simulation capability that helped



start the process leading to our current mental and linguistic abilities. Mammals in general exhibit at least two kinds of involuntary simulation behavior—dreams and play. While a cat is dreaming, a center in the brainstem (the locus coeruleus) blocks the motor nerves so that the cat's dream thoughts are not translated into action. If this brainstem center is disabled, the sleeping cat may walk around the room, lick itself, catch imaginary mice, and otherwise appear to be acting out its dreams. There is a general belief that dreaming is important for memory consolidation in people and this would also be valuable for other mammals. Similarly, it is obvious that play behaviors in cats and other animals have significant adaptive value.

p0530 Given that mammals do exhibit involuntary displacement in dreams, it seems that only one evolutionary adaptation would have been needed to achieve our ability to imagine situations of our choice. Suppose that the mammalian involuntary simulation mechanisms were augmented by brain circuits that could explicitly control what was being imagined. This kind of overlaying a less flexible brain system with one that is more amenable to control is a hallmark of brain evolution. Now, hominids who could do detached simulations could relive the past, plan for the future, and would be well on their way to simulating other minds. Understanding other minds would then provide a substrate for richer modeling and communication, just as Tomasello and others have suggested.²

p0540 And what about Fodor's contention that people cannot learn new concepts? We have suggested a slight variant: people can only learn new concepts that map to things they already know. This is not as exciting as Fodor's version, but it has two significant advantages. First of all, it is true. In addition, it provides a framework for studying individual and cultural development as the interplay of genetics and experience. For people who take the science of the mind seriously, a unified approach to cognitive science is the only game in town.

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²Notice how close this is to the pragmatist view of Note 1.



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