It’s the Body, Stupid: Concept Learning According to Cognitive Science

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I. How concepts are learned

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, here focusing on the question of concept learning. The particular perspective on concept learning we advocate 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.

Leaving aside for now Fodor's argument (Fodor 1988) that concepts cannot be learned (which turns on definitions of *learn* and *concept*), there remains an ancient and profound scientific question. If we exclude divine intervention, 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. Since 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 can not learn any concepts that go beyond the combinatorial possibilities afforded by genetics.

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 (Boroditsky In Press, Majid et al 2004, etc.) 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.

A coherent and plausible picture of human concept learning is arising from combining biological, behavioral, computational, and linguistic insights. This account draws upon another biological problem for which the answer is now known in great detail – immunology. Animal immune systems are remarkably good at generating antibodies to combat novel antigens that invade the body. The raging question used to be: is this a process where the killer antibody is selected from a fixed innate repertoire or does the system somehow manufacture a custom antibody, instructed by the intruder. The full answer is beyond the scope of this paper (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).

A "primitives plus composition" account of conceptual structure offers a way out of Fodor's dilemma, but it still 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 this. There is indeed an internal foundation for our concepts and it is us. As part of our animal heritage, we 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 grounded in these 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.

As may already be obvious, we will be using facts about language in our discussion of concepts and thought. Words express concepts and evoke them in the listener. Much of conscious internal thought appears to be self-talk and, as we will point out, there are many well established findings relating words and mental 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 Pragmatists[1] 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 *goa*l and *continuity*. We will not worry about the possibility that there are concepts that can not be described in words.

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.

II. Evidence for embodied language and simulation semantics

Experiments based on the unified approach to conceptual structure reveal that 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 of their embodied content.

As a first 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 what you know about grapefruit, that is in order 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. Accessing this knowledge takes the form of subjective sensory and motor experiences associated with the concept; reflecting on the carvability of a grapefruit involves the internal creation of motor and sensory experiences of carving a jack-o-lantern out of a grapefruit, and so on. 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. We can simulate from multiple perspectives - it is quite different to imagine pushing, being pushed, or observing third party pushing.

The notion that mental access to concepts is based on the internal recreation of previous embodied experiences is supported by recent brain research, showing that motor and pre-motor cortex areas associated with specific body parts (i.e. the hand, 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, when subjects perform a lexical decision task (deciding 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*), the motor cortex areas responsible for mouth versus leg versus hand motion exhibited more activation, respectively. This result has been corroborated through Transcranial Magnetic Stimulation work (Buccino et al 2005). Tettamanti et al. (2005) have also shown through an imaging study that passive listening to sentences describing mouth versus leg versus hand motions activates corresponding parts of pre-motor cortex (as well as other areas).

Behavioral studies also offer convergent evidence for the automatic and unconscious use of perceptual and motor systems during language use. Recent work on spatial language (Richardson et al. 2003, Bergen, Matlock, and Narayan ms) has found that listening to sentences with visual semantic components can result in selective interference with visual processing. While processing sentences that encode upwards motion, like *The ant climbed*, subjects take longer to perform a visual categorization task in the upper part of their visual field (deciding whether an image is a circle or a square). The same is true of downwards-motion sentences like *The ant fell* and the lower half of the visual field. These results imply that understanding spatial language evokes visual imagery that interferes with visual perception.

A second behavioral method (Glenberg & Kashak 2002) tests the extent to which motor representations are activated for language understanding. When subjects are asked to perform a physical action, 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 actions 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 towards 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.

A third method, used by Stanfield & 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* versus *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 downwards), it took subjects less time to perform the task than when it was in a different orientation (e.g. horizontal). The same result was found when subjects were just asked to name the object depicted. Zwaan and colleagues also found that when sentences implied that an object would have different shapes (e.g. an eagle in flight versus at rest), subjects once again responded more quickly to images of that object that were coherent with the sentence - having the same shape as they had in the sentence.

A final method investigates whether utterances take longer to process when the scenes they describe take longer to mentally scan. Matlock (In press) demonstrates that the time subjects took 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* was processed faster when it followed a paragraph describing an athletic young man who jogs along the path than when it followed one describing an old man who had difficulty walking all the way down the path. Similarly, characteristics of the path itself like its distance or difficulty to navigate were found to influence processing time in the same direction - the longer it would take the mover to travel the path, the longer it took subjects to process the fictive motion sentence. This work once again implies that processing language makes use of a dynamic process of mental simulation.

These convergent results suggest a major role for embodied perceptual and motor experiences in language understanding. Language understanders automatically mentally imagine, or simulate, 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 (towards 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 the very brain mechanisms responsible for perceiving the same percepts or performing the same actions.

Mental simulation has an equally important role in other higher cognitive functions like memory and imagery. Several recent neural imaging studies complement existing behavioral evidence that recalling motor experiences recruits cognitive mechanisms responsible for performing the same motor actions, by activating the same parts of the brain's motor system, just as recalling perceptual experiences, both in the visual and auditory domains, makes use of perceptual modality-specific neurocognitive structures (Barsalou 1999, Wheeler et al. 2000, Nyberg et al. 2001). Similarly, 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 recruits brain structures responsible for performing the actions or perceiving the percepts that appear in the mind's eye.

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 as 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 (Pecher et al 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.

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. Talking to oneself internally, even without producing any speech or speech gestures, is itself demonstrably a sort of mental simulation. 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. Empirical measures confirm that the motor and auditory systems are activated during inner speech. For one, covert speech results in brain activation whose lateral localization correlate with that of overt, actual speech (Baciu at 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, since it can itself drive mental simulation of another sort. Suppose 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,* this internally generated language, like language a hearer might perceive, drives a simulation of the described events. This simulated experience thus facilitates simultaneous or future performance of the same task.

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).

There are obviously limits to the extent to which previous experience can define simulation. If meaning, as argued here, involves the activation of motor and perceptual (and other) representations of past experiences, 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), like 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, 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." (Kosslyn et al. 2001:635). 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. While it is constrained and informed by these experiences, compositional and other creative capacities allow departures from them.

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).

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 model specifies 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.

Since 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 focus in the next section on how embodied concepts are learned.

III. Learning basic words/concepts

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. From birth, children exhibit imitation and other social skills (Meltzoff and 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, this volume).

First words vary significantly across individuals, but most English-speaking children's first words (Figure 1) consist predominantly of concrete nouns, like *truck* and *ball* and social-interactional words, like *up* and *more* (Bloom 2000, Tomasello 2000). The grounding of concrete nouns in direct experience is clear, but importantly, using social-interactional words is equally bound to embodied experience. A child who utters *up!* is not reflecting 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 is lifted. Often children also acquire concrete verbs like *get* and *sit*. It's 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, this volume).

	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**

Figure 1. The words learned by most 2-year olds in a play school (Bloom 1993)

If all children acquired words and concepts identically, then even a progression from more directly experienced to more abstract could plausibly be accounted for as the emergence of innate concepts. However, across languages and cultures, systematic differences in the character of children's experience, due to linguistic differences, among others factors, 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 clear from context. Thus, if it's clear to both interlocutors that they're 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 *He is throwing it* – it would suffice to say the equivalent of *Is throwing*. As a result, children growing up learning Korean and Chinese, among other languages, 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 universal is that children start by labeling concepts that are directly accessible to them through experience.

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. 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; and the schemas corresponding to its meaning. Moreover, language directs a learner to attend to certain aspects of their perceptual and motor experiences in order to make categorical linguistic distinctions (McDonough et al. 2003).

A strong test of this hypothesis is to build a computational model that realizes the hypothesis and see if it exhibits the right behavior. David Bailey (1997) faced the problem of building a program that needed to capture the conceptual differences across languages in order to learn word meanings for hand actions. Building in too many assumptions would preclude learning some languages and leaving everything unspecified gives the program no chance at all of learning. Bailey's solution on what structure to build into the system was to base it 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.

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 the model and, we believe also in the brain, is *parameterization*. A motor action such as grasping involves many coordinated neural firings, muscle contractions, etc., 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, etc. 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.

Figure 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. As discussed above, what we can consciously know about our own actions can be described by a relatively small number of features. People do not have direct access to the elaborate neural networks that coordinate our actions. This parameterization of action is one key to the success of the program.

A second critical feature of the model is the schematic representation of actions, called executing schemas (X-schemas), shown at the bottom of Figure 2. In addition to parameters like force, actions are characterized by control features. For example, some actions are repetitive, some conditional, etc. Depicted in Figure 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 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).

Also notice in Figure 2 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 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.

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 Terry Regier (1996) learned spatial relation terms across languages that conceptualize these quite differently, including Mixtec, which bases such language on body parts. In general, there seems to be no barrier to explaining in detail how children could learn those words of their language whose semantics is directly embodied. These include words based on emotional and social cognition as well as perception, action, and goal seeking. Basic words and their concepts label variants and combinations of core neural capabilities. In the next section, we suggest how this gets extended to the learning and use of words for abstract and technical concepts.

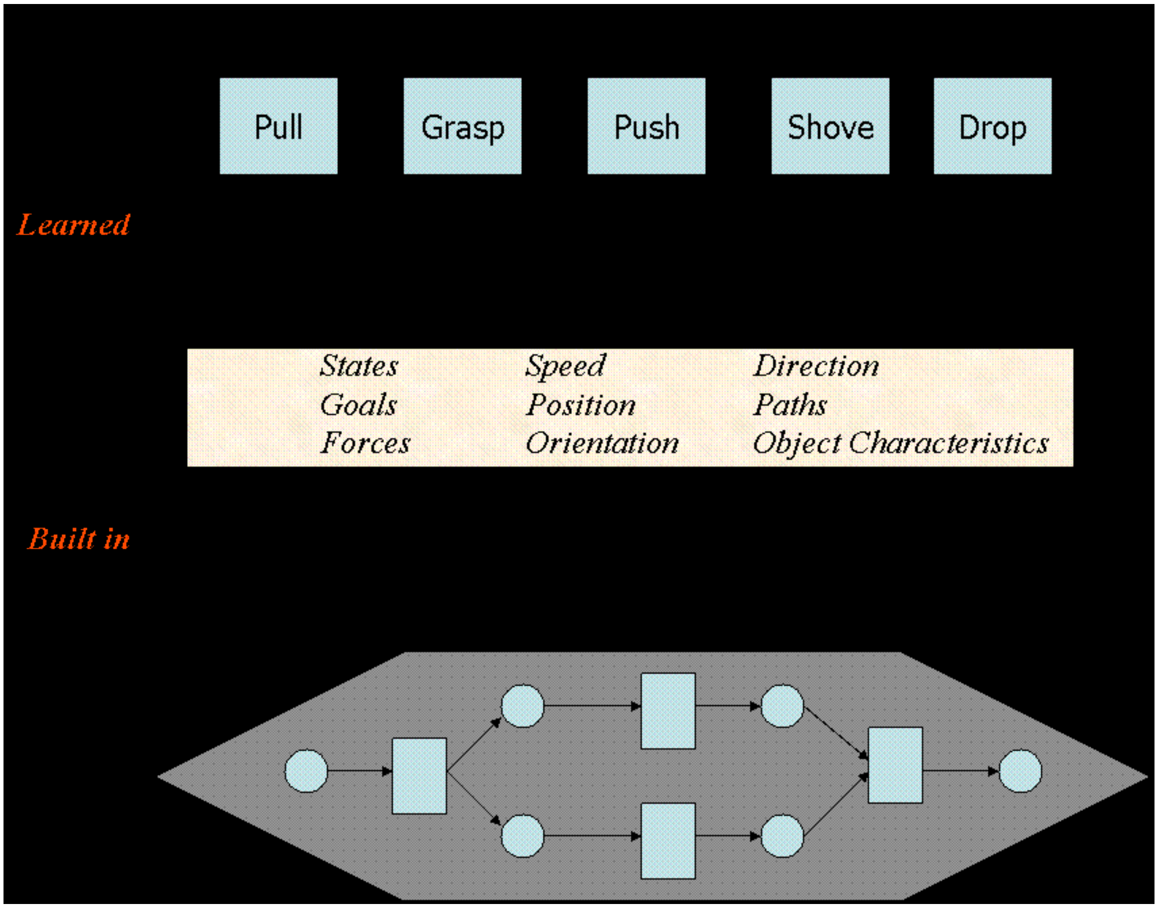

Figure 2. Overview of Bailey's Model for Learning Action Verbs

IV. Learning and Using Abstract and Technical Words and Concepts

We have argued that language about directly experienced aspects of the world, and the concepts it links to, derive from schematization over concrete 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.

Existing concepts are used to produce novel ones through composition mechanisms like: conjunction (a narwhal is easily learned to be like a beluga with a long unicorn-like tusk); modification (a llama is like a camel with only one 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 shown above, language drives perceptual, motor, and affective simulation. This simulation is experience that itself 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). Nevertheless, the mental experience driven by that language, and reproduced using the relevant neural circuits, is a sufficient basis for some conceptual reorganization.

In fact, because of the brain's massive connectivity and spreading activation, concepts are never learned or activated in isolation - each of us has a rich structure of interrelated concepts. We are also continuously composing or "blending" concepts. For example, quite different hues are suggested by red hair, red pencil, red light, etc. 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.

The best studied of mechanisms for grounding abstract concepts is through mappings 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, 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, worn out, among many other metaphorical construals.

A large body of research from the past twenty-five years provides convergent evidence that abstract conceptual domains are not only talked about in terms of these concrete ones, but are actually thought about in terms of them as well. Early work in a Cognitive Linguistic framework (Lakoff & Johnson 1980, Lakoff 1993) provides three main types of evidence that metaphor is not just describing-as, but conceptualizing-as. First, there is systematicity in metaphorical language – 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. Second, this metaphorical language is productive. It is not just due to conventionalized metaphorical meanings associated with particular words, but rather is regularly used in novel ways, as in *The human stem cell research disintegrated in the light.* Third, not just language but also reasoning transfers from a concrete conceptual domain to an abstract one. 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's slippery or bulky – or to a property of the understander – they don't have sufficient mental skills to get their head around it. More recently, an important fourth type of evidence has appeared, showing that language users activate concrete source domains when thinking about abstract target domains (Gibbs et al. 1997, Boroditsky 2000, Boroditsky 2001, Tseng et al To Appear).

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 and 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 milk in a glass, the higher level of the milk; the more blocks 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 of the latter on the basis of the former. As the learner subsequently develops, the two domains are distinguished – adults know that abstract quantity does not always correlate with physical height. But the conceptual and linguistic links between the two domains persist, as the experimental evidence shows.

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's 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 distribution of actual mappings whereby theories are described and understood as buildings is partial – only certain aspects of buildings are mapped onto theories –the physical structure of buildings (foundation, support, and buttresses), and their persistent erectness. 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 correlational basis. 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 persist.

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.

V. Conclusions

We have provided a sketch 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 this:

1) Our core concepts are based on the neural embodiment of all our sensory, motor, planning, emotional, social, etc. abilities, most of which we share with other primates. This is a huge, but not unbounded, collection of primitives.

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.

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, metaphor, etc.

4) Domain relations, particularly conceptual metaphors, are the central compositional operations that allow us to learn technical and other abstract concepts.

5) We understand language by mapping it to our accumulated experience and imagining (simulating) the consequences.

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 don't get 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". Children come to language learning with a very rich collection of conceptual primitives and composition rules.

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 and 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.

Given that language is embodied and that grammar maps from sound to experience, the child's problem in learning grammar is not overwhelming. She learns basic words as labels for her experience as we pointed out in Section 3. The key insight for learning compositional rules of grammar is that the job of a grammar rule is to specify conceptual composition. The child already understands the scene conceptually and only needs to hypothesize what it is about the linguistic form that licenses the known conceptual composition. Of course these early hypotheses about grammar rules are sometimes wrong, and the usual learning processes of test, 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 Chang (forthcoming). Some additional descriptions of ECG and its applications can be found in Chang et al. (2002) and Bergen and Chang (2005)

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 become fluent language users and conceptual thinkers? This is a subject of considerable current research, most notably in Michael Tomasello's group in Leipzig (http://www.eva.mpg.de/english/profil.htm). There is unlikely to be a single feature that explains all uniquely human mental attributes, but Tomasello has identified one feature that is clearly important - the ability to understand other minds. From our perspective this 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.

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 coereleus) 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.

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 choosing. 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 and no one would be surprised to find another instance of this mechanism. 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]

And what about Fodor's contention that people can not 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, unified cognitive science is the only game in town.

References

Aziz-Zadeh, Lisa, Luigi Cattaneo, Magali Rochat and Giacomo Rizzolatti. 2005. Covert Speech Arrest Induced by rTMS over Both Motor and Non-motor Left Hemisphere

Frontal Sites. Journal of Cognitive Neuroscience 17(6).

Baciu, Monica V.,Christophe Rubin, Michel A. Décorps, Christoph M. Segebarth. 1999. fMRI assessment of hemispheric language dominance using a simple inner speech paradigm. NMR in Biomedicine 12(5): 293-298

Bailey, D. N. Chang, J. Feldman, S. Narayanan (1998). Extending Embodied Lexical Development. Proceedings of the Twentieth Annual Meeting of the Cognitive Science Society COGSCI-98, Madison.

Bailey, David. 1997. When Push Comes to Shove: A Computational Model of the Role of Motor Control in the Acquisition of Action Verbs. UC Berkeley Ph.D. Thesis.

Barsalou, L.W. (1999). Perceptual symbol systems. Behavioral and Brain Sciences, 22, 577-609.

Barsalou, L.W., & Wiemer-Hastings, K. (2005). Situating abstract concepts. In D. Pecher and R. Zwaan (Eds.), Grounding cognition: the role of perception and action in memory, language, and thought (pp. 129-163). New York: Cambridge University Press.

Bergen, Benjamin and Nancy Chang. 2005. Embodied Construction Grammar in *Simulation-Based Language Understanding*. In Jan-Ola stman and Miriam Fried (Eds.), Construction Grammars: Cognitive grounding and theoretical extensions.

Bergen, B., T. Matlock, & S. Narayan (In Prep). Linguistic cues for perceptual simulation.

Boroditsky, L. (2000). Metaphoric Structuring: Understanding time through spatial metaphors. Cognition, 75(1), 1-28.

Boroditsky, L. (2001). Does language shape thought? English and Mandarin speakers' conceptions of time. Cognitive Psychology, 43(1), 1-22.

Boroditsky, L. (in press). Linguistic Relativity. To Appear in the Encyclopedia of Cognitive Science. MacMillan Press.

Bloom, Lois. 1993. The Transition from Infancy to Language: Acquiring the Power of Expression. New York: Cambridge University Press.

Bloom, P. (2000). How children learn the meanings of words. Cambridge, MA: MIT Press

Buccino G., Riggio L., Melli G., Binkofski, F. , Gallese V., and Rizzolatti G. (2005) Listening to action-related sentences modulates the activity of the motor system: a combined TMS and behavioral study. Cog. Brain Res. 24: 355-363.

Carroll, Lewis. 1865. Alice's adventures in wonderland.

Chang, N., J. Feldman, R. Porzel, and K. Sanders. 2002. Scaling Cognitive Linguistics: Formalisms for Language Understanding. Proc. 1st International Workshop on Scalable Natural Language Understanding. Heidelberg, Germany.

Choi, Soonja. 2000. Caregiver input in English and Korean: use of nouns and verbs in book-reading and toy-play contexts. J. Child Lang. 27:69-96.

Chomsky, N. 1980. Rules and Representations. Oxford: Basil Blackwell.

Churchland, Patricia Smith. 2002. *Brain-Wise: Studies in Neurophilosophy*: MIT Press.

Dancygier, B., and E. Sweetser. 2005. *Mental spaces in grammar: conditional constructions*. New York: Cambridge University Press.

Edelman, Gerald. 1987. *Neural Darwinism. The Theory of Neuronal Group Selection*. Basic Books, New York.

Ehrsson, H.H., S. Geyer, & E. Naito (2003). Imagery of voluntary movement of fingers, toes, and tongue activates corresponding body-part specific motor representations. *Journal of Neurophysiology, 90*, 3304–3316.

Fauconnier, G. 1985.*Mental spaces: Aspects of meaning construction in natural language.* MIT Press.

Fauconnier, G. and Turner, (2002). M. *The Way We Think: Conceptual Blending and the Mind's Hidden Complexities.* Basic Books

Feldman, J. 2006.*From Molecule to Metaphor: A Neural theory of Language*. MIT Press

Feldman, J. and Narayanan, S. (2004). Embodied Meaning in a Neural Theory of Language. *Brain and Language*, 89, 385-392.

Fodor, J. 1998. *Concepts: Where Cognitive Science Went Wrong*. Oxford University Press

Gallese, V. and Lakoff, G. (2005). The Brain's Concepts: The Role of the Sensory-Motor System in Reason and Language. Cognitive Neuropsychology.

Glenberg, A. M., Havas, D., Becker, R., & Rinck, M. (2005). Grounding Language in Bodily States: The Case for Emotion. In R. Zwaan and D. Pecher (Eds.) The grounding of cognition: The role of perception and action in memory, language, and thinking. Cambridge: Cambridge University Press.

Glenberg, A. & M. Kaschak (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9*, 558-565.

Gibbs, R. W., Bogdanovich, J. M., Sykes, J. R., & Barr, D. J. (1997). Metaphor in idiom comprehension. Journal of Memory & Language, 37, 141-154.

Grady, J.E. (1997). THEORIES ARE BUILDINGS revisited. Cognitive Linguistics 8, (4), pp.267-290.

Hauk, O., I. Johnsrude, & F. Pulvermüller (2004). . Somatotopic representation of action words in human motor and premotor cortex. *Neuron, 41(2),* 301-7.

Hockett, CF (1960) The origin of speech. Scientific American, 203:88-96.

Hoff, E. (2001) *Language Development, 2nd Ed.* Brooks/Cole,

Johnson, Christopher R. 1999. Constructional grounding: The role of interpretational overlap in lexical and constructional acquisition. Ph.D. dissertation, University of California, Berkeley.

Kaup, B. & Zwaan, R. A. (2003). Effects of negation and situational presence on the accessibility of text information. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*,

Kosslyn, S., G. Ganis, & W. Thompson (2001). Neural foundations of imagery. Nature Reviews *Neuroscience, 2,* 635 -642.

Lakoff, G. (1993). The contemporary theory of metaphor. In A.Ortony (Ed.),Metaphor and Thought, 2nd edition. Cambridge University Press.

Lakoff, George and Mark Johnson. 1980. Metaphors we live by. Chicago: University of Chicago Press.

Livesay J, Liebke A, Samaras M, Stanley A. 1996. Covert speech behavior during a silent language recitation task. Perceptual Motor Skills 83(3 Pt 2):1355-62.

Lotze, M., P. Montoya, M. Erb, E. Hülsmann, H. Flor, U. Klose, N. Birbaumer, & W. Grodd (1999). Activation of cortical and cerebellar motor areas during executed and imagined hand movements: An fMRI study. *Journal of Cognitive Neuroscience, 11(5),* 491-501

Majid, A., Bowerman, M., Kita, S., Haun, D. & S. Levinson (2004). Can language restructure cognition? The case for space. Trends in Cognitive Sciences, 8(3), 108-114.

Mandler, Jean M. 1992. How to build a baby: II. Conceptual primitives. Psychological Review 99(4): 587-604

Matlock, T. (in press). Fictive motion as cognitive simulation. Memory & Cognition.

McDonough, L., Choi, S., Mandler, J. (2003) Understanding spatial relations: Flexible infants, lexical adults. Cognitive Psychology, 46, 229-259.

Meltzoff, A. N., & Prinz, W. (2002). The imitative mind: Development, evolution, and brain bases. Cambridge, England: Cambridge University Press.Moon, C, Cooper, R P and Fifer, W P (1993). Two–day olds prefer their native language. Infant behaviour and development. 16, 495–500.

Narayanan, S. (1997) KARMA: Knowledge-based Action Representations for Metaphor and Aspect. UC Berkeley Ph.D. Thesis.

Narayanan, S. (1999). Moving Right Along: A Computational Model of Metaphoric Reasoning about Events. *Proceedings of the National Conference on Artificial Intelligence AAAI-99*. Orlando, Florida.

Nyberg, L., K.-M. Petersson, L.-G. Nilsson, J. Sandblom, C. Åberg, & M. Ingvar, M.2001. Reactivation of motor brain areas during explicit memory for actions. *NeuroImage, 14*, 521-528.

Pecher, D., Zeelenberg, R., & Barsalou, L.W. (2003). Verifying properties from different modalities for concepts produces switching costs. Psychological Science, 14, 119-124

Pecher, D., Zeelenberg, R., & Barsalou, L.W. (2004). Sensorimotor simulations underlie conceptual representations: Modality-specific effects of prior activation. Psychonomic Bulletin & Review, 11, 164-167

Pinker, S. & Jackendoff, R. (2005) What's special about the human language faculty? *Cognition, 95(2),* 201-236.

Porro C., M. Francescato, V. Cettolo, M. Diamond, P. Baraldi, C. Zuian, M. Bazzocchi, & P. diPrampero (1996). Primary motor and sensory cortex activation during motor performance and motor imagery: a functional magnetic resonance imaging study. *Journal of Neuroscience 16,* 7688–7698.

Pulvermueller, F., M. Haerle, & F. Hummel (2001). Walking or Talking?: Behavioral and Neurophysiological Correlates of Action Verb Processing. *Brain and Language, 78,* 143–168.

Richardson, D., M. Spivey, K. McRae, & L. Barsalou (2003). Spatial representations activated during real-time comprehension of verbs. Cognitive Science, 27, 767-780.

Regier, T. 1996. The Human Semantic Potential: Spatial Language and Constrained Connectionism. Cambridge: MIT Press.

Rizzolatti G, Craighero L. 2004. The mirror-neuron system. Annual Review of Neuroscience 27:169-92.

Solomon, K. O., & Barsalou, L. W. (2001). Representing properties locally. Cognitive Psychology, 43, 129-169.

Solomon, K.O., & Barsalou, L.W. (2004). Perceptual simulation in property verification. *Memory & Cognition*, *32*, 244-259.

Stanfield, R. & R. Zwaan (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science*, *12,* 153-156.

Tettamanti, M., Buccino, G., Saccuman, M.C., Gallese, V., Danna, M., Scifo, P., Fazio, F., Rizzolatti, G., Cappa, S.F. and Perani, D. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. J Cogn. Neurosci. 17: 273-281.

Tomasello, M. (2000). First steps in a usage based theory of first language acquisition. Cognitive Linguistics

Tseng, Meylysa, Yiran Hu, Wen-Wei Han, and Benjamin Bergen. To Appear. "Searching for happiness" or "Full of joy"? Source domain activation matters. Proceedings of the 31st Annual Meeting of the Berkeley Linguistics Society.

Wheeler, M., S. Petersen & R. Buckner (2000). Memory’s echo: Vivid remembering reactivates sensory specific cortex. *Proceedings of the National Academy of Science of the*

U.S.A. 97, 11125–11129.

Zwaan, R, R. Stanfield, & R. Yaxley (2002). Do language comprehenders routinely represent the shapes of objects? *Psychological Science, 13*, 168-171.

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[1] From 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 prehuman 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."

[2] Notice how close this is to the Pragmatist view of Note 1.