

# CHAPTER X

## EVOLUTION, EMBODIMENT AND THE NATURE OF THE MIND

MICHAEL L. ANDERSON,

DEPARTMENT OF PSYCHOLOGY, FRANKLIN & MARSHALL COLLEGE, LANCASTER, PA (USA)  
AND INSTITUTE FOR ADVANCED COMPUTER STUDIES, AND PROGRAM IN NEUROSCIENCE AND  
COGNITIVE SCIENCE, UNIVERSITY OF MARYLAND, COLLEGE PARK, MD (USA)

*This is an edited, abridged transcript of the remarks made in my keynote address to the 2006 Cognition conference “Beyond the brain: Embodied, situated and distributed cognition”. The material is drawn primarily from (Anderson, 2003; 2007a; 2007b; 2007c), and these articles should be consulted for a more detailed treatment of the themes introduced in this talk.*

Although it is customary in a talk on embodied cognition to begin with all the reasons we should doubt the more traditional approaches to the study of the mind, I am going to ignore that custom for both merely practical and more substantive reasons. The merely practical reason is the time allotted; the more substantive reason is the fact that we ought by now to be in a position where the embodied, situated and distributed approach(es) to the study of the mind are seen not primarily as criticisms of the prevailing paradigm, but as established, vibrant and fruitful research programs in their own right, needing no justification other than their own success. I intend to make this assumption in all my future work, and I urge you to do the same.

Instead I would like to do three main things:

1. First, introduce you to—perhaps even convince you to adopt—an approach to the mind motivated primarily by evolutionary considerations. I’ll do that by laying out four principles for the study of the mind from an evolutionary perspective, and four predictions that they suggest. As you’ll see, this evolutionary perspective is completely compatible with, although broader than, the embodied cognition approach.
2. Then I want to look at one prediction in depth, the idea that the brain evolved by exaptation—reusing existing functional units, and combining them in novel ways to generate new cognitive capacities.
3. Finally, I’ll try to lay out some of the implications, both of the in-depth example, and of the more general approach.

### **1. Four general principles and predictions for evolution and cognition**

So, what if we did try to take more seriously than is typical the notion that the brain—and, not incidentally, the body it is housed in, and therefore the mind that these fashion—*evolved*? There is certainly much that could be said on this theme, but I will focus on only four points by introducing four “facts” about the evolution of cognition, a prediction that each supports, and some examples of or evidence for that prediction.

*Fact 1: Cognition evolved in specific environments*

*Prediction 1: Cognition will take advantage of the concrete structure or enduring features of those environments.*

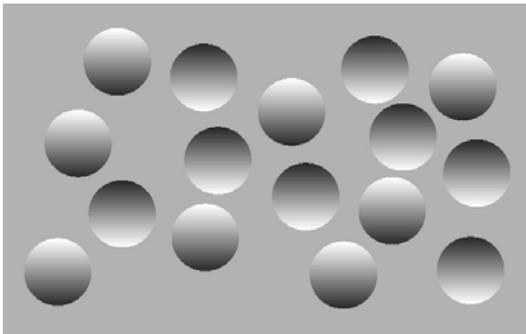
*Example 1a: Learning the solar ephemeris.*

As is well known, bees forage for food, and, upon their return to the hive, communicate the location of the food source by dancing a symbolic dance. The foraging bee moves in a figure eight pattern, wagging as it

reaches the center of the figure. The orientation of the waggle relative to vertical specifies the direction of the food source relative to the sun (that is, it gives the solar bearing of the food source), while the number of waggles gives the approximate distance of the food source from the hive (Frisch, 1967; Gallistel, 1999). However, as the day progresses, bees do not fly in the same direction with respect to the sun, but rather adjust their bearing to compensate for the sun's movement, so that, for instance, if told of a food source in the morning, and freed to fly to it in the afternoon, they will appropriately adjust their bearing. Strikingly, the foraging bee is able to give (and other bees are able to use) the solar bearing of the source even when the sun is difficult to see, as on heavily overcast days (Brines and Gould, 1982), and a times when the sun cannot be, and never has been seen, as at midnight (Lindauer, 1957; 1960). This is because they know the solar ephemeris—the position of the sun as a function of the time of day (Dyer and Dickinson, 1994; Gallistel, 1999). However, the solar ephemeris is different for different times of the year, and at different latitudes, and therefore it must be learned. Further, the angular motion of the sun is not constant, but accelerates near solar noon, and slows down in the morning and evening. Thus, learning the ephemeris is a difficult problem, especially given the short (3-4 week) lifespan of foraging bees. As a solution to this problem, evolution has built in to the system responsible for learning the solar ephemeris a set of assumptions corresponding to some invariants: that the sun is in the opposite position in the morning and in the afternoon, and that the azimuth travels through 180 degrees at noon. That is, bees are innately equipped with an ephemeris step function, in which the sun stays at a constant azimuth position in the eastern sky during the morning hours, and switches to the opposite position in the western sky where it remains during the afternoon. Through experience the ephemeris function is quickly brought into line with local conditions (Dyer and Dickinson, 1996). Thus, the invariants of the environment are taken advantage of to simplify what would otherwise be an extremely difficult learning problem.

*Example 1b: Built-in assumptions in perception.*

Consider also the myriad ambiguities in perception. If the visual system were always calculating possibilities *de novo*, the fairly simple figure below (fig. 1) could depict quite different things. Take only the circle in the upper left corner of the rectangle. If the light source is coming from above, that pattern of shading indicates a convex shape; if it is coming from below, it indicates a concave shape; and if it is coming from the side, it indicates a flat but gradually shaded surface.



In fact, however, normal perceivers experience no such ambiguity, nor a need to choose between competing possibilities—surely a blessing if one is being chased and needs to find a cave to escape to. Instead, there is a built-in bias to interpret visual stimuli as if the light source were from above, something that becomes readily apparent as you spin this picture and watch the shapes go from convex, to flat, to concave and back again. Given the way our environment is illuminated, this is a pretty good (but not infallible!) assumption; taking advantage of it simplifies visual processing by ruling out many alternate interpretive possibilities.

*Fact 2: Cognition evolved in organisms with pre-existing sets of behavioral possibilities, instincts, habits, needs, purposes, and the like.*

*Prediction 2: Cognition will incorporate and take advantage of overt behaviors.*

*Example 2a: Epistemic actions.*

Epistemic actions are those taken for the purpose of changing the environment so as to lighten cognitive load—for instance arranging a hand of cards to better see patterns, writing something down to aid memory, or, in the famous case tested by Kirsh and Maglio, rotating Tetris pieces to more easily assess their fit with a target (Kirsh and Maglio, 1994).

*Example 2b: Scaffolding*

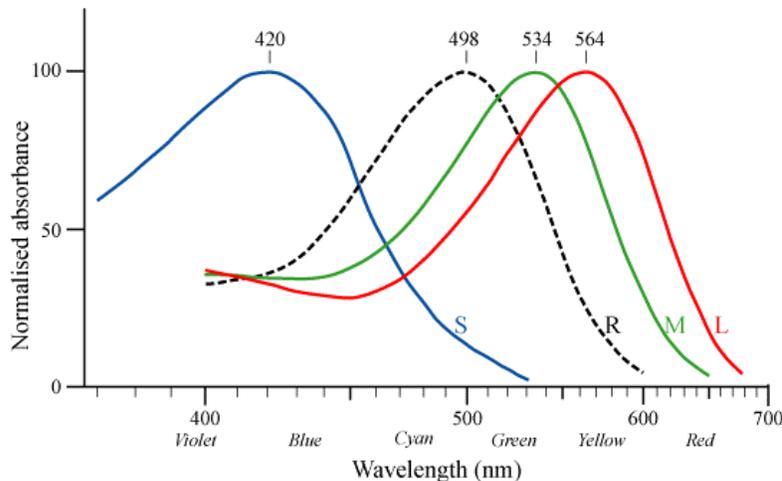
A further development along these lines is what Clark (1997) has called “scaffolding”: that is, the creation of relatively stable environmental structures—i.e. cognitive tools—to aid in cognitive actions. The simplest such example is the creation of signs and other labels, e.g. in the supermarket or on the highways, to allow for easier navigation. Note that this is an instance of the intentional creation of local, perceptible environmental features, to be used to guide action with respect to distal, imperceptible objects, and as such is just a further development and complication of a widespread, natural cognitive strategy. More complex examples include Arabic numerals and the various arithmetic routines they permit; the abacus and other more complex computing machinery; social structures in general, and role-based, task-oriented social structures in particular (such as manufacturing lines, command structures, or management teams; on these latter examples see Hutchins 1995).

*Fact 3: Cognition evolved in organisms with specific physical attributes, bodies of a certain type with given structural features.*

*Prediction 3: Cognition will be shaped by and take advantage of these features for cognitive ends.*

*Example 3a: Color-concept structure*

The relatively simple idea here is that there should be traces of the particulars of bodily structure at the level of cognitive contents or operations. One example due to Lakoff and Johnson (1999) is the “center-periphery” structure of color concepts, with a focal or canonical hue grounding the main concept (fire-engine red), and other related hues being defined in terms of the focal hue, can be traced to the response curves of our color-vision system. Focal hues correspond to visual frequencies of maximal response, with peripheral hues trailing off in the directions of other response-determined color foci.



*Example 3b: Cognitive mapping of planning on locomotion*

In a rather more complex case, Lakoff and Johnson argue that planning, i.e., the ability think through a process and act in a concerted way to meet some goal, owes a great deal to locomotion. Now, it should come as no surprise to anyone (whether a committed EC researcher or not) that our basic spatial concepts (“up”, “down”, “forward”, “back”, etc.) are deeply tied to our orientation in and movement through the

physical world. However, according to Lakoff and Johnson, many different domains of thinking depend on these basic spatial concepts via internal and metaphorically based cross-domain “mappings” (think of an upright person, the head of an organization, facing the future, being on top of things), and these mapped domains thereby inherit a kind of reasoning—a sense of how concepts connect and flow, of what follows from what—which has its origin in, and retains the structure of, our bodily coping with space. Thus, returning to the case of planning, consider the mapping “purposes are destinations”: we imagine a goal as being at some place ahead of us, plot a route, imagine obstacles, and set landmarks to track our progress. In this way, our thinking about purposes (and about time, and states, and change, and many other things besides) is rooted in our thinking about space. And, indeed, neural imaging studies suggest that mental planning can activate higher motor areas even when the planning itself involves no motor activity (Dagher, et al., 1999).

*Fact 4: As with the other bodily organs, the organ(s) of cognition evolved to solve specific problems of bodily function in light of already evolved (and evolving) organs.*

*Prediction 4: Cognition will rely on the operation of other functional units, organs and organ systems.*

*Example 4a: Phonological loop for working memory*

One instance of such reliance on which there has been a fair amount of work is in the apparent use of sensorimotor resources to support working memory. As the evidence has been reviewed in detail by Margaret Wilson (2001), I’ll only provide a brief summary. The experiments in question typically involve the presentation of multiple items (words or letters) either visually or auditorily, with the task being to remember these items, in order. The question of interest is what kind of processing supports this ability, and there is a great deal of evidence supporting some version of the Baddeley and Hitch model of working memory, which posits that working memory has both verbal and visuospatial components, among others (Baddeley and Hitch, 1974; 1994, Baddeley, 1986; 1995). Basically, the Baddeley and Hitch model says that one strategy for remembering such lists involves (silently) saying them to one’s self (producing a “phonological loop”), which engages brain areas typically used both in speech production and in audition.

A pattern of findings supports the existence of a phonological loop, a strategy that engages both inner “speaking” and inner “hearing” to support working memory. First, there is poor recall of similar sounding terms; second, there is poor recall of longer words; third, there is poor recall if the subject is made to speak during the maintenance period; and fourth, there is poor recall when the subject is exposed to irrelevant speech during the maintenance period. Moreover, imaging studies have found that such memory tasks cause activation in areas typically involved in speech production (Broca’s area, left premotor cortex, left supplementary motor cortex, and right cerebellum) and in phonological storage (left posterior parietal cortex) (Awh et al., 1996).

As Wilson writes, in this case it appears that

...sensorimotor processes are run covertly to assist with the representation and manipulation of information, in the temporary absence of task-relevant input or output. Such an arrangement would make sense, given our evolutionary heritage from creatures whose neural resources were devoted largely to perceptual and motor processes. Indeed, given that we have such resources, it would be odd if we did not exploit them whenever possible to assist in off-line cognitive processing. (pp. 44-5)

*Example 4b: Action-sentence compatibility effect*

An even more striking example of the reliance of cognitive processes on existing functionality is the action-sentence compatibility effect (Glenberg and Kaschak, 2002), which suggests the involvement of the motor system in language understanding. To demonstrate this interesting interaction between comprehension and motor control, Glenberg and Kaschak asked subjects to indicate whether a given sentence made sense or not by making a response that required a movement either toward or away from their bodies (e.g. reaching for a button). They found that response times were longer in cases where the required movement ran counter to a movement suggested by the sentence itself (e.g. where the response required a movement toward the body, and the sentence, e.g., “Close the drawer” indicated a movement away from the body, or vice-versa), and that this was true even when the “movement” indicated by the sentence was abstract, as in

the transfer of information from one party to another (e.g. “You told Ann about the party.”). A general explanation of this effect would be that the comprehension of the sentences involved a motor simulation of the action they describe, thus “priming” the system to move in one way, rather than another. More particularly, Glenberg and Kaschak posit that understanding language involves combining the affordances of the sentence elements, and judging the “doability” of the action corresponding to the meshed set of affordances. A doable action indicates a comprehensible sentence.

These results are intriguing and highly suggestive, yet, as Glenberg and Kaschak readily admit, there is much more work to be done.

In summary, our results demonstrate that the understanding of imperative, double-object and dative constructions is grounded in action. Given that language almost certainly arose to facilitate coordination of action, it is not surprising that there is an observable remnant of that history. The results also raise the intriguing possibility that much, if not all, language comprehension is similarly grounded. Although substantial work needs to be done to secure that possibility, that work may well be rewarded by an account of language and meaning firmly anchored in human experience. (p. 564)

Even from this brief treatment of only a few examples, what leaps out are the many ways in which cognition depends upon marshalling and deploying existing resources—resources of a highly various sort, internal, external, structural, behavioral—as a way of simplifying and solving different cognitive problems.

From this perspective, the brain as a whole begins to look less like a calculating machine, and more like the assembly coordinator of what Wilson and Clark (forthcoming) call “transient extended cognitive systems”—a series of temporary cognitive machines put together to perform some complex task like long division. This is not to say that the brain never calculates over representations—surely that is an important mechanism underlying many of its capacities—but that is not what emerges from an evolutionary perspective as the brain’s most salient contribution to many cognitive processes.

One other thing to notice here is that many of the main insights of embodied and situated approaches to cognition follow naturally from the evolutionary perspective. However, on the evolutionary perspective, the use of existing resources for cognitive ends happens not just in real time, driven by transient cognitive needs, but also over evolutionary time, driven by more permanent pressures. So we turn now to take a more in-depth look at this particular issue.

## **2. Prediction four in-depth: massive redeployment in the evolution of the brain**

One way of cashing out, in the particular domain of brain evolution, the general notion that cognition evolved to (and that it is part of its basic nature to) take advantage of existing resources—cognitive, bodily and environmental—is to posit that the brain evolved by a kind of exaptation (Gould and Vrba, 1982) in which existing neural resources were re-used by later developing cognitive functions, while leaving intact the original functionality. This is the essence of the massive redeployment hypothesis (Anderson, 2007a; 2007c), and from it follow four specific predictions:

1. Redeployment—the re-use of existing circuits for new cognitive ends—will turn out to be the *norm* when it comes to the functional topography of the brain.
2. There will be significant redeployment both within and between traditional cognitive domains (e.g. perception, motor control, language, memory, etc.).
3. More recent cognitive functions will utilize more, and more widely scattered brain areas.
4. Evolutionarily older brain areas will be deployed in more cognitive functions.

Prediction 1 is really just a restatement of the hypothesis, and requires no further explanation. Prediction 2 is suggested even by some of the examples we have seen already—sensorimotor support of working memory, and motor control resources involved in language understanding and abstract planning—and says essentially that we shouldn’t expect given neural resources to be *dedicated* to specific cognitive domains. Looking at the idea from the other side, it means that we shouldn’t expect cognitive domains to be very localized, contained in specific brain regions devoted to domain-specific tasks. Indeed, and this brings us to

prediction 3, the newer a given cognitive function is, the more recently it evolved, the *less* localized we should expect it to be. The reason for this is simple: the more neural components there are when a given cognitive capacity is evolving, the more likely that one of them will already serve some purpose useful for the emerging capacity, and there is little reason to suppose that the most useful areas will be grouped together; indeed, there is less and less reason to suppose this as evolutionary time passes, making available more functions supported by more components. Thus, newer cognitive functions will typically be supported by more, and more widely scattered, neural components than phylogenetically older functions. Finally, we come to prediction 4, which we would expect to be the case for quite similar reasons. The longer an neural component has been around the more likely it will have proved useful to some later-evolving cognitive capacity, and to have been incorporated into the functional network of brain regions supporting the new task. Naturally this will not be true for every brain region, since a given area may have evolved to serve a very particular purpose of little use in later developments. But it should be generally the case that the older an area is, the more cognitive functions it supports.

In the interest of space, I will not detail here the methods used to investigate these four predictions; please refer to the above-cited papers for that. In outline, however, what I did was look at 135 brain-imaging studies in four cognitive domains: language, perception, attention and mental imagery. I counted the number of brain regions (Brodmann areas) activated by each task in each domain, and, noting where those regions were, calculated how far away each was from the other regions activated by the task (that is, how many Brodmann areas separated them). In addition, I counted how many tasks, in how many domains, activated each brain region.

The results were quite striking. Of the brain areas that were found to be active in at least one imaging study, each was found to be active in an average of 13 studies, nearly one in 10 of the 135 studies analyzed. Moreover, these activations were not typically limited to a single cognitive domain. Over 90% of the brain areas found to be active by a study in one domain, were also activated by at least one task in another domain; over 80% had activations in three domains; and half were activated by tasks in all four domains. This rather strongly suggests that redeployment is the norm in the brain, and that evolution shows little respect for the boundaries between cognitive domains.

In addition, the studies showed that each cognitive task activated an average of 5.97 brain areas. Perceptual tasks activated 4.88, attention 5.26, imagery 6.39 and language 7.81. Looking at the scatter of activated areas, the average number of unactivated brain areas separating the activated ones was 2.89 for all tasks. Broken down by cognitive domain, we get attention 2.13, perception 2.71, imagery 2.97, and language 3.82. This puts us in a position to evaluate prediction 3, that more recent cognitive functions will utilize more, and more widely scattered brain areas; and, indeed, the prediction seems borne out by the data. If we assume that language is the youngest cognitive domain, and perception and attention are the oldest, we would expect to see significant differences in the number of brain areas involved, and in their distance from one another when comparing language with perception and with attention—and this is exactly what we do see. The differences between all other possible comparisons are not statistically significant.

This leaves prediction 4, that evolutionarily older brain areas will be deployed in more cognitive functions. This direct relationship between the phylogenetic age of a brain area and its frequency of redeployment is the most difficult to accurately establish, for the simple reason that there is little consensus on the relative evolutionary age of various cortical structures. Thus, for this measure, we can employ an admittedly crude simplifying assumption: all things being equal, structures in the front of the brain will be evolutionarily more recent than structures in the back of the brain. Given this assumption, we can look for—and we find—a significant linear correlation between the horizontal position of the activated brain area (on the axis drawn front to back), and the number of tasks by which the area is activated. Although the finding is based on an admittedly questionable indirect measure, it is nevertheless quite striking to have found such a correlation.

### **3. Summary and implications**

Although the massive redeployment hypothesis clearly has some specific implications for such things as the overall functional structure of the brain, the modularity hypothesis, and the practice of cognitive neuroscience, for the purposes of this talk—given the venue—I will focus instead on some more general

implications of the evolutionary perspective, including the (apparent) fact of massive redeployment, for the nature of cognition, especially as it relates to embodied, embedded and situated approaches.

First, thinking about the nature of cognitive functions, the approach seems to suggest that they will be highly integrated with one another, sharing resources, and cooperating at various levels. Somewhat more speculatively, this integration may entail a degree of ‘likeness’ between the functions (Anderson, in press). That is, to the degree to which planning and language understanding are integrated with—rely on some of the same resources as—motor control, they may be in some important way *like* motor control (and vice versa, see, e.g. Gorniak and Roy, 2006). This insight promises to change our understanding of the nature of, and the boundaries between, cognitive domains.

Second, thinking about the nature of cognition, we should be led to say that thinking is something organisms (not brains, or parts of brains) do—cognition is an activity of a whole organism in its environment. This is in part a result of the fact that cognition is set up so as to utilize the resources of the brain, body and environment for its own ends, and partly a result of the fact that, as part of thus utilization, overt behaviors often become proper parts of cognitive processes. The cognitive subject is the full, embodied, embedded, situated, acting, reacting, and proacting organism.

Third and finally, thinking of the nature of the mind, we should conclude that the mind is *embodied* and *embedded*—that it is grounded in, relies upon, marshals, and manipulates bodily, environmental, social, and other resources for cognitive ends.

## References

- Anderson, M.L. (2003). Embodied cognition: A field guide. *Artificial Intelligence* 149(1): 91-130.
- Anderson, M.L. (2007a). Evolution of cognitive function via redeployment of brain areas. *The Neuroscientist*, 13(1): 13-21, 2007.
- Anderson, M.L. (2007b). How to study the mind: An introduction to embodied cognition. In F.Santoianni and C. Sabatano, eds. *Brain Development in Learning Environments: Embodied and Perceptual Advancements*. (Cambridge: Cambridge Scholars Press).
- Anderson, M.L. (2007c). The massive redeployment hypothesis and the functional topography of the brain. *Philosophical Psychology*, 21(2): 143-174.
- Anderson, M.L. (in press). Massive redeployment, exaptation, and the functional integration of cognitive operations. *Synthese*.
- Awh, E., Jonides, J., Smith, E.E., Schumacher, E.H., Koeppel, R.A., & Katz, S. (1996). Dissociation of storage and rehearsal in verbal working memory: Evidence from positron emission tomography. *Psychological Science*, 7: 25-31.
- Baddeley, A.D. (1986). *Working Memory*. Oxford: Oxford University Press.
- Baddeley, A.D. (1995). Working memory. In: M.S. Gazzaniga, ed. *The Cognitive Neurosciences*. Cambridge, MA: The MIT Press. 755-64.
- Baddeley, A.D. & Hitch, G. (1974). Working memory. In: G.H. Bower, ed. *The Psychology of Learning and Motivation*. Hillsdale, NJ: Earlbaum. 647-67.
- Baddeley, A.D. & Hitch, G. (1994). Developments in the concept of working memory. *Neuropsychology*, 8: 485-93.
- Brines, M. L. and Gould, J. L. (1982). Skylight polarization patterns and animal orientation. *J. Exp. Biol.* 96: 69–91.
- Clark, A. (1997). *Being There: Putting Brain, Body, and World Together Again*. Cambridge, MA: MIT Press.
- Dagher, A., Owen, A., Boecker, H., and Brooks, D. (1999). Mapping the network for planning. *Brain* 122: 1973-1987.

- Dyer, F. C. and Dickinson, J. A. (1994). Development of sun compensation by honeybees: how partially experienced bees estimate the sun's course. *Proc. Natl. Acad. Sci. USA* 91: 4471-.
- Dyer, F. C., and Dickinson, J. A. (1996). Sun-compass learning in insects: Representation in a simple mind. *Current Directions in Psychological Science* 5: 67-71.
- von Frisch, K. (1967) *The Dance Language and Orientation of Bees*. Cambridge, MA: Harvard University Press.
- Gallistel, C. R. (1999). The replacement of general-purpose learning models with adaptively specialized learning modules. In M.S. Gazzaniga, Ed., *The Cognitive Neurosciences* 2d. ed. (1179-1191). Cambridge, MA: MIT Press.
- Glenberg, A. & Kaschak, M. (2002). Grounding language in action. *Psychonomic Bulletin and Review* 9: 558-565.
- Gorniak, P. and Roy, D. (2006). Perceived affordances as a substrate for linguistic concepts. Proceedings of the twenty-eighth annual meeting of the Cognitive Science Society.
- Hutchins, E. (1995). *Cognition in the Wild*. Cambridge, MA: MIT Press.
- Kirsh, D. and Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science* 18: 513-549.
- Lakoff, G. and Johnson, M. (1999). *Philosophy in the Flesh: The Embodied Mind and its Challenge to Western Thought*. New York: Basic Books.
- Lindauer, M. (1957). Sonnenorientierung der Bienen unter der Aquatorsonne und zur Nachtzeit. *Naturwissenschaften*, 44: 1-.
- Lindauer, M. (1960). Time compensated sun orientation in bees. *Cold Spring Harb. Symp. Quant. Biol* 25: 371-8.
- Wilson, M. (2001). The case for sensorimotor coding in working memory. *Psychonomic Bulletin and Review* 8: 44-57.
- Wilson, R.A. & Clark, A. (forthcoming). How to situate cognition: Letting nature take its course. In M. Aydede & P. Robbins (eds), *The Cambridge Handbook of Situated Cognition*. Cambridge: Cambridge University Press.