CHAPTER FIVE

How to study the mind: An introduction to embodied cognition

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Basics of Embodied Cognition

EC treats cognition as a set of tools evolved by organisms for coping with their environments. Each of the key terms in this characterization—tool, evolved, organisms, coping, and environment—has a special significance for, and casts a particular light on, the study of the mind. EC thereby foregrounds the following six facts:

(1) Cognition, like every other adaptation, has an *evolutionary history* that can be useful in understanding its function;

(2) Perhaps more importantly, cognition evolved because it was adaptive—that is, it enhanced survival and reproductive success primarily by *allowing more effective coping* with the environment;

(3) Cognition evolved in specific environments, and its solutions to survival challenges can be expected to *take advantage of the concrete structure or enduring features of those environments*;

(4) Cognition evolved in *organisms with specific physical attributes*, bodies of a certain type with given structural features, and can therefore be expected to be shaped by and to take advantage of these features for cognitive ends (for some interesting examples, see claim (12)b, below). Note in particular that the primary physical organ system supporting cognition, the central nervous system, is *also*, and of course not coincidentally, the organ system responsible for perception and the coordination and control of action, making quite natural the motto (to paraphrase Clark, 1998) that the mind is first and foremost the control system for the body. Indeed, cognition is to be seen precisely as a complex adaptation *of* the body's control system to aid survival and reproductive success. Moreover, these physical features were not immutable,

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and we know that there has been co-evolution of physical and cognitive attributes, as for instance between the primate, and human, hand and brain (Wilson, 1998). Thus, what this means is not *just* that physical attributes (bigger brains, better neurons, etc.) changed over time, and were preserved if they better served cognition, but that cognition evolved in light of, and in the context of, a given physical system, and therefore that certain *cognitive* attributes would have been preserved just in case they (better) served that particular organism, whether or not that feature or solution would be optimal by other measures or appropriate for other organisms;

(5) Cognition evolved in organisms with *pre-existing sets of behavioral possibilities*, instincts, habits, needs, purposes, and the like. The evolutionary process would have taken advantage of these possibilities, preserving some and altering others, and incorporating them into its solutions—for instance, taking advantage of certain pre-existing dispositions to manipulate the environment or one's relation to it, which dispositions may have evolved for reasons unrelated to cognitive enhancement.

(6) As with the other bodily organs, (co-)evolved to solve specific problems of bodily function in light of already evolved (and evolving) organs, we shouldn't be surprised to find the organ(s) of cognition to:

   a. Be composed of basic functional units with limited variation (e.g. neurons);

   b. Involve repeated and redundant functional structures at slightly higher levels of organization (e.g. XOR gates);

   c. Evince high degrees of specialization at the highest levels of organization (e.g. specialized modules). This means, among other things, that there need be no universal cognitive solutions;

   d. Rely for their function on the operation of other functional units, organs and organ systems, (e.g. interactions between cognition, action, and perception, see claims (3)-(5), above); and

   e. Be coordinated without requiring extensive central control (which does not rule out central control in specific cases).

For a charming example of the re-utilization of existing behaviors for new ends, to instances of which EC researchers should be especially attuned, consider the case of the mole cricket, detailed by Turner (2000) and discussed by Clark (2002). As everyone knows, the cricket chirps to attract mates; but as everyone also knows, crickets are small, which limits the amplitude of the sound they can produce. The mole cricket's solution to this problem is to build a burrow of a very particular shape, known as a Klipsch horn, consisting of a hollow bulb underground, connected by a narrow constriction to a flared tunnel (the "horn") opening into the air. The cricket sits at the intersection of bulb and horn, chirps, adjusts the burrow, and tries again, until the right resonant frequency is experienced. The resulting instrument permits a 1700% increase in the efficiency of the muscle-power to sound transformation, producing a chirp that can be heard 600 meters away. Now, the following is admittedly speculation—albeit speculation of the sort I am suggesting that EC researchers do and ought to engage in—but I rather suspect that the original purpose of the burrows, their reason for being preserved in some form, had much more to do with safety from predators than with mate attraction. However, once that behavioral disposition to dig was established as a resource for evolution, it became available for other uses, and was modified over time with the results detailed above. This is just the sort of recycling of existing physical structures and behavioral dispositions we should expect also to find in cognition (see claims ((9)-(10), below).

Thus, to return to the list of key terms offered above, cognition is a *set of tools* with specific, complementary, and cooperative functions, *evolved* because these cognitive tools were adaptive, individually or in concert, for the *organism*, individually or in concert with other organisms.[2] These organisms were possessed of specific and co-evolving physical features and behavioral dispositions, perhaps initially present as part of overall strategies for *coping* with a *specific environment* in non- or proto-cognitive ways, but nevertheless there to be utilized and adapted to the changing needs of the evolving creature. Not only would cognitive adaptations have taken advantage of and developed in light of the organism's physical or structural features, but they would also have developed in the context of reliable *environmental* features (water currents, or tides, or solar movements, or

[2] It is worth keeping in mind, although I will not emphasize it here, that one of the environmental resources that can be taken advantage of is the presence of (and potential cooperation with, whether intentional or symbiotic) other organisms.

abundant shelter, or soft earth, etc.), and we should expect these to be exploited in cognitive adaptations, as well.

Evolutionary-Embodied Cognition as an organizing framework for EC

I think that most (and probably all) of the various characterizing propositions of EC offered over the years can be expressed in terms of the principles above, and doing so offers the advantage of clarifying *why* cognition should be as it is. Consider, for instance, the following claims (7)-(12), adopted from (Wilson, 2002). The initial quote in each item is from Wilson; the discussions that follow are my own.

(7) "*Cognition is situated*. Cognitive activity takes place in the context of a real-world environment, and inherently involves perception and action." That much of cognition can be described this way follows directly from the stance outlined above, especially the notion that much of cognition is adapted to serve the needs of survival, and would have taken advantage of stable environmental structures to simplify and speed cognitive processing. Situated cognition emphasizes the fact that a great deal of cognitive activity takes place in the context of, and actively involves, repeated interactions with the environment (see claim (9), below), and ought to be understood largely in terms of tight, fast, perception-action feedback loops. Note that I am using qualifiers like "much", "a great deal" and "largely". I agree with Wilson's general criticisms that it is neither evolutionarily nor cognitively plausible to describe all cognitive activity as situated in this way (see Anderson, 2003).

(8) "*Cognition is time-pressured*. We are 'mind on the hoof' (Clark, 1997), and cognition must be understood in terms of how it functions under the pressure of real-time interaction with the environment." This, too, can be understood as an integral part of the claim that cognition developed as a sophisticated coping mechanism in a potentially hostile, changing environment. Given the need for at least some fast-acting, effective ("intelligent") survival mechanisms, we should expect some aspects of cognition to be highly reactive and environmentally driven. Perhaps more importantly, the time-pressure on cognition can be an important explanation for claim (9), below.

(9) "*We off-load cognitive work onto the environment*. Because of limits on our information-processing abilities (e.g. limits on attention and working memory), we exploit the environment to

reduce the cognitive workload." Wilson emphasizes the case of epistemic actions (Kirsh and Maglio, 1994), which are actions 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, or, in the case tested by Kirsh and Maglio, rotating Tetris pieces to more easily assess their fit with a target. However, it seems to me that epistemic actions exemplify only one of at least two broad categories of methods by which organisms use the environment to simplify cognitive tasks. Thus:

a. *Organisms exploit stable environmental features to simplify cognitive tasks*. The most obvious (and, in its way, unremarkable) case of this strategy is when an organism learns to exploit natural representations and other indicators of various kinds. Elephants appear to know that thunder (and, more particularly, thunder that follows lightning in ever-shorter intervals) indicates approaching rain (Masson and McCarthy, 1996); likewise, hunting animals can use scent trails, or visual signs like burrow holes, to find desired prey. Although the ability to exploit causal regularities in this way is very simple, it does draw attention, and should attune us, to the widespread use of the local and perceptible to stand in for things distal and perhaps perceptually unavailable; insofar as this can allow behaviors to be guided by local, perceptible environmental features, it can reduce (albeit not, in all cases, eliminate) the need for more abstract, detailed, internal representations. Somewhat more profound is the case where stable features (including stable dynamic features) of the environment are used to simplify learning itself, with the most famous and well-studied case being the honeybee's learning of 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, waggling 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.

b. *Organisms change the environment to simplify cognitive tasks*. As noted already, epistemic actions belong in this category. These can include the examples mentioned above, which involved creating spatial arrangements to simplify perceptual tasks, but also such things as counting with one's fingers, or using paper and pencil to store intermediate results in a long math or logic problem, thereby permitting more complex mental derivations.[3] 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[4]; 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). Each of these can allow for very complex (mental and physical) activities, by simplifying the task demands at each step (in the case of mathematical algorithms) or at each person-node (in the case of social structures). There is not room here to discuss any of these examples in more detail; for now it is enough to recognize the picture that is emerging—of an intelligence characterized, enhanced, and in some sense constituted by the organism's dynamic and ongoing interaction with the environment, some of it artificially enhanced—and to point out here again that the fact that cognition would take advantage of, direct, and enhance an organism's abilities to interact with and change its environment is precisely what one should expect when thinking of cognition from an evolutionary standpoint.

(10) "*The environment is part of the cognitive system*. The information flow between mind and world is so dense and continuous that, for

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[3] Wilson calls examples of this latter sort "symbolic off-loading". See also (Clark, 1997).

[4] Not to mention written language more generally. Clark (1997) also emphasizes that language itself can be seen as a kind of *natural* scaffold—a cognitive tool that greatly enhances cognitive ability and simplifies cognitive tasks or all sorts. On this, see (Carruthers, 2002).

scientists studying the nature of cognitive activity, the mind alone is not a meaningful unit of analysis." This has been one of the more contentious claims to come out of the EC approach, and I'll not try to defend it in its strong form. What is right, or at least illuminating, about the claim flows from an analogy that can be made between mental and physical tools. When trying to analyze the actions of an organism, it can sometimes make sense to define the acting system in question as a whole including both the body and the tools of the organism. Turner (2000) argues for just such a "physiological" interpretation of the mole-cricket burrow (see the discussion, above). Likewise, it can be said that one doesn't understand the dynamics of spear throwing while using an atalatal[5] without including the atalatl in the calculation of the system dynamics—the throw is performed not by the hunter, but by the hunter plus atalatl. Merleau-Ponty (1962) famously took this one step further by noting that the blind man can be said to feel, not with the hand holding the cane, but *with the cane*; there is a sense in which the cane becomes a part of the body, and the locus of sensation is extended to the tip of the cane. The claim is that the experience of the blind man is not one of feeling bumps in the hand and *inferring* from these the presence of certain textures or obstacles at the tip of the cane; rather, the cane as artifact recedes into the phenomenological background, and the signals transmitted by the motions of the cane are immediately interpreted in terms of—are felt as—the textures and obstacles in the world as present at the tip of the cane.[6] In such cases the actions, or the character of the perceptions, of the organism are best understood by including the tools with the body to form a single (acting, perceiving) system for analysis. The case is likewise when considering the cognitions of an organism as performed in the context of continual interactions with the environment, and/or with the help of the cognitive tools mentioned in claim (9), above. Here, too, it can make sense to treat the cognition as performed by an extended system including the actions, environmental changes, and external scaffolds employed by the thinking agent. In is in

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[5] A specialized stick with one end held in the hand, and the other fitted into the end of a spear, effectively increasing the length of one's throwing arm, and therefore increasing the torque with which one can throw a spear.

[6] Consider, in this regard, the difference between holding an apple in one's hand and feeling it to be an apple, and counting the five bumps on its bottom and inferring it to be a Red Delicious (Clancey, 1997).

> such terms that one should understand the various “mind isn’t in the head” slogans of EC.

Before continuing with claims 11 and 12, it is worthwhile to pause here for further discussion of this issue. That it is sometimes best to understand the organism as thinking, not just with (in) its head, but also with its body and its environment, is an extremely important point, one that is fundamental to the EC approach to the study of mind. However, to say that this is fundamental to the EC approach to the *study* of mind is to stop short of making a deep ontological or metaphysical claim about the mind *itself*. EC is clearly right to claim that the most fruitful analysis of cognitive phenomena can sometimes involve the postulation of a cognitive system that extends beyond the boundaries of a given agent’s brain and body. In particular, if the cognitive *process* being studied involves the use of external tools, environmental changes, or cognitive scaffolding to simplify or otherwise assist in representation, calculation, decision-making, or some other cognitive activity, then there seems to be no principled reason to deny that, insofar as the actions and changes in the environment are proper parts of a cognitive process, the cognitive system implementing the process can be usefully considered as extending beyond the brain (or CPU) of the agent in question. However, it always remains possible to draw boundaries between the parts of such an extended system; moreover, at least some cognitive processes *do* take place “in the head”, even when they are smaller parts of other cognitive processes that involve the body and environment in various ways. Thus, depending on one’s particular research focus, there will always be cases where adopting more restrictive boundaries (let’s call *this* the cognitive process of interest) is the more sensible choice. Thus, the claim that the mind is always and everywhere, in its essence, *distributed and extended*, has not won out, and, if I may say so, this is as it should be. Indeed, it seems to me not only that such essentialist claims suffer from the usual difficulties attendant to all projects of metaphysical definition, but also that there is something in them that runs counter to the primarily empirical, pluralistic, evolutionarily-grounded spirit central to EC. Some, perhaps very many, of the evolutionary solutions to cognitive problems involve tight perception-action feedback loops, the reliance on, and even the intentional alteration of, environmental structures to reduce cognitive load, and the use of cognitive scaffolds. But other solutions may be more intensively computational, logical, and symbolic, and better understood and explained in these terms.[7] The existence of neither class of solution undermines the significance or

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[7] Note that this does *not* imply that such solutions are “disembodied”. See claim (12), below.

utility of the other, nor can either be considered to define the "real foundation" or essence of the mind; to fight about such things is to fight about nothing.

(11) "*Cognition is for action*. The function of the mind is to guide action, and cognitive mechanisms such as perception and memory must be understood in terms of their ultimate contribution to situation-appropriate behavior." As this entire essay is motivated by this very thought, I'll not elaborate further on it here, except to say that I am in accord with the general thrust of Wilson's critique of narrow versions of this claim, such that would require direct and immediate connections between cognition and action in every case. Not every individual cognitive move directly supports or subserves some given overt action. The point is rather that the cognitive system is, and evolved because it is, a behavioral control system, albeit one that often utilizes representations, concepts and other very complex and flexible machinery.[8]

(12) "*Off-line cognition is body-based*. Even when decoupled from the environment, the activity of the mind is grounded in mechanisms that evolved for interaction with the environment—that is, mechanisms of sensory processing and motor control." As with claim (9), above, it is worth breaking this claim into two different, related theses.

a. *The nature and structure of perception, cognition, and its constituents (e.g. representations and concepts), as well as procedures of thinking, logical rules, and the like, depend on (or are grounded in) the nature, structure and behaviors of the body*. Some of the most interesting and well-known examples of this claim come from the work of Lakoff and Johnson (1980; 1999). They note, for instance, that the "center-periphery" structure of color concepts, with a focal hue grounding the main concept, and other related hues being defined in terms of the focal hue, can be traced to the neural response curves of our color-vision system. Focal hues correspond to visual frequencies of maximal neural response, with peripheral hues trailing off in the directions of other neurally-determined color foci. In a rather more

[8] For an account of representations taking behavior-guidance (rather than information-content) as its point of departure, see (Rosenberg and Anderson 2004; Anderson and Rosenberg, forthcoming; Anderson, forthcoming)

complex case, they 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. According to Lakoff and Johnson, such cross-domain mappings are a pervasive element of our thinking, whether on-line or off.

b. *Even off-line cognition, thinking that is out of temporal sync with, or takes place without physical interaction with the environment, is body-based*. Once the overall claim is split into two, this latter point follows easily from the former. In so far as a concept has its roots in the structure of the body, or one's customary modes of thinking are grounded one's coping with space, or one's moral judgments share their structure with one's experience with food purity, then cognition will still owe a great deal to the body, however distant one's current thinking may be from the immediate demands of, or however little it currently requires interaction with or consideration of, one's body and its environment. Moreover, as Wilson emphasizes, many instances of abstract cognition apparently utilize the sensory-motor system in even more direct ways than do these cross-domain mappings. Thus do Svensson, Lindblom and Ziemke (forthcoming) argue that “many, if not all, higher-level cognitive processes are body-based in the sense that they make use of (partial) simulations or emulations of sensorimotor processes through the re-activation of neural circuitry that is also active in bodily perception and action.” For instance, working memory appears to involve resources normally tasked for speech perception and production (Wilson, 2001), mental planning can activate higher motor areas even when the planning itself involves no motor activity (Dagher, et al., 1999),[9] and the existence of mirror neurons strongly suggests that off-line motor simulations are an important part of our interpretation of the actions of others (Rizzolatti, et al., 1996). In an even more striking example, the action-sentence compatibility effect (Glenberg and Kaschak, 2002) 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. 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. One explanation of this effect would be that the comprehension of the sentences involved a motor simulation of the action, thus “priming” the system to move in one way, rather than another. Finally, it is worth at least mentioning the growing body of evidence uncovered by Susan Goldin-Meadow and others regarding the interrelations of speech and gesture, and the cognitive importance of the latter (see, e.g., Goldin-Meadow, 2003). According to Goldin-Meadow, gesture is typically used not

[9] Note that this finding complements and reinforces the “purposes are destinations” mapping proposed by Lakoff and Johnson.

just to signal different moments in the learning process (e.g. to index moments of decision or re-consideration in a problem solving routine),[10] but also appears to have utility in *advancing* the learning process, perhaps by providing another, representational format that might facilitate the expression of ideas currently unsuited (for whatever reason) to verbal expression. Here again, this sort of re-use and re-tasking of existing resources for cognitive ends will come as no surprise to the cognitive scientist who takes a broadly evolutionary standpoint.

Some differences between EC, situated cognition, and reductive biology

We are, at this point, in a good position to appreciate the following fact, important to a correct understanding of EC: one of the things that distinguishes the thesis of *embodied* cognition from situated cognition, on the one hand, and reductive neurophysiology on the other, is that it is central to EC that the body has a special status in and for cognition at several organizational and structural levels.[11] It is not only neurons (or sub-neuronal structures) that matter; nor is it only the interaction of organism and environment. Rather, structure and function, action and interaction, matter from top to bottom, affecting the nature and content of mental entities and events.

Some different meanings for, and levels of embodiment are nicely laid out in (Ziemke, 2002).[12] Although Ziemke, in his illuminating if ultimately inconclusive discussion, lays out these various conceptions as a way of determining the minimal requirements for a system to be considered “embodied”, or to support EC, here we will instead take each as a suggestion for the various ways in which, or levels at which, a cognitive system’s physical instantiation and situation can affect or shape its cognitive processes.

13. *Embodiment as structural coupling*. To explain this aspect of embodiment, Ziemke cites the definition given by Quick et al. (1999), which says that “A system X is embodied in an environment

[10] Note that this aspect of gesture alone is of potentially great utility for educators, for by attending not just to speech but to gesture, it should be possible to better track the changing learning states of a given pupil.

[11] Thus, identifying these various significant levels of organization, and their specific cognitive impact, is one of the most important research projects in EC. It is the central component of what I call the *physical grounding project* (Anderson, 2003).

[12] See also (Anderson, 2003) sections 3.1-3.4.

E if perturbatory channels exist between the two." That is, if there is the bi-lateral possibility that each system can affect (perturb, change the states of) the other, they are structurally coupled. As Ziemke notes, as a restrictive definition of embodiment, meant to distinguish systems that are embodied from those that are not, this leaves much to be desired. Still, it is probably something like a necessary condition for embodiment, and may be useful insofar as it grounds questions useful to the EC researcher, such as: in what ways might the number and character of the perturbatory channels between X and E affect X's cognitive processes? How might a cognitive system take advantage of, or even alter, these channels so as to aid in cognition? We have discussed some specific examples that answer these questions in claim (9), above

14. *Historical embodiment*. This aspect of embodiment emphasizes that the character of an agent's cognitive processes owes a great deal to continuous and repeated interaction with the environment, not just in the evolutionary history of the species (as we have been primarily emphasizing here) but also in the lifetime of the individual agent. The agent adapts to its environment over both evolutionary and individual time (this latter adaptation, of course, being learning), and its cognitive processes thereby reflect the fact and character of this interaction. Here again, the task for the EC researcher is to identify the specific ways in which such interactions matter to, and are reflected in, the character of the agent's cognition.

15. *Physical, organismoid, and organismic embodiment*. These aspects of embodiment express three increasingly restrictive levels of physical instantiation: unrestricted physical instantiation; physical instantiation in an organism-like body (possessing some similar degree of autonomy and sensorimotor capacity as a living organism); and physical instantiation in an actual living body. Although each of these appear very different from the standpoint of restrictively defining the minimal amount or type of embodiment required to support EC, they are for our purposes the same, in that their utility is to draw attention to the ways in which the specific physical characteristics of a cognitive system affect the nature and character of its cognitive processes. We have discussed some examples in claim (12), above.

16. *Social embodiment*. This aspect of embodiment emphasizes that at least some organisms are coupled not just with a physical environment, but also with a social one, and that therefore there

exist various "perturbatory channels" between the organism and the social world that also matter to the character of its cognitive processes. Indeed, in some ways, nearly everything that has been said in this essay while emphasizing the relations between the organism and the physical environment (e.g. in claims (7)-(12)) can be recapitulated while emphasizing the interactions between the organism and its social environment. For instance, social organisms off-load cognitive work onto the environment not just by manipulating spatial arrangements or storing intermediate mathematical results on paper, but by utilizing social structures in various ways, e.g. asking an expert, assigning a task, or working with others in various complex ways. This is an immense topic in its own right, and beyond the scope of the current essay, but see, e.g. (Lave, 1988; Rogoff and Lave, 1984).

How to study the mind: a few basic methodological principles

The main exegetical work of this article has been to outline and illuminate the main ideas behind the EC approach to the study of mind; the main argumentative task has been to show that these various ideas follow naturally from an evolutionarily grounded perspective on the study of animal cognition. I hope I have been able to do both in a concise and helpful manner. By way of a conclusion, I would like to enumerate a few basic principles for the study of the mind from the EC perspective; these might be understood as the methodological "morals" following from claims (1)-(5), above.

17. Be mindful of the need to (eventually) provide evolutionary accounts of observed cognitive phenomena, as this can sometimes affect the sort of mechanisms one is tempted to propose to account for the observations.

18. Attune oneself to look for the *selective advantage*, or other evidence for the *adaptivity*, of cognitive attributes, and always ask whether and how the attributes in question increase the effectiveness of behavior.

19. Be aware of the many ways in which the environment can serve (and/or is serving) as a resource for cognitive activity.

20. Look for ways that physiology is incorporated in, reflected by, evolved to better serve, or otherwise affects cognitive functioning.

21. Be aware that the original purpose—the originally selected function—of given behaviors may not fully exhaust current

purposes, and that cognition, once developed in rudimentary form, was itself a source of selection pressure. More to the point, expect to see instances in which pre-existing behavioral tendencies have been tuned to serve cognitive ends. Further, recognize that the ability to manipulate the environment, to cause both temporary and more permanent changes, provides an immense cognitive resource, deeply and fundamentally involved in even the highest-order cognitive activities.

22. In biological matters, variety and specialization are to be expected, as is exhibited both by the multitude of species, and by the variety of bodily organs serving their various functions for the organism. Thus, don't expect a single kind of solution to every cognitive problem; there is no single account of thinking. Neither anticipate hierarchical, centralized control systems nor highly distributed, loosely coordinated processes; neither predict the prevalence of representation-intensive solutions nor of representation-free ones. The various combinations of organism, environment, and problem are, although not unique, nevertheless too numerous and specific to yield a single strategy in response. On the other side of the coin, one *should* expect a great deal of structure and organization within functionally specialized systems, and inter-reliance and co-evolution between them. Moreover, some problems are so common (locomotion), and some solutions so good (the eye), that we should expect in some cases to see convergence on a limited number of viable solutions. Representation, in the most general sense, may be one of these.

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