TOPICS
TOPICS IN COGNITIVE SCIENCE

Topics in Cognitive Science 2 (2010) 705–715

ISSN: 1756-8757 print / 1756-8765 online
DOI: 10.1111/j.1756-8765.2010.01089.x

Cognitive Ecology

Edwin Hutchins

Department of Cognitive Science, University of California San Diego

Received 2 March 2009; received in revised form 7 September 2009; accepted 23 October 2009

Abstract

Cognitive ecology is the study of cognitive phenomena in context. In particular, it points to the web of mutual dependence among the elements of a cognitive ecosystem. At least three fields were taking a deeply ecological approach to cognition 30 years ago: Gibson's ecological psychology, Bateson's ecology of mind, and Soviet cultural-historical activity theory. The ideas developed in those projects have now found a place in modern views of embodied, situated, distributed cognition. As cognitive theory continues to shift from units of analysis defined by inherent properties of the elements to units defined in terms of dynamic patterns of correlation across elements, the study of cognitive ecosystems will become an increasingly important part of cognitive science.

Keywords: Units of analysis for cognition; Ecological psychology; Ecology of mind; Activity theory; Embodied cognition; Situated cognition; Distributed cognition; Brain–body–world systems; Human culture

1. Choosing units of analysis for cognition

Cognitive ecology is the study of cognitive phenomena in context. Elements of cognitive ecology have been present in various corners, but not the core, of cognitive science since the birth of the field. It is now being rediscovered as cognitive science shifts from viewing cognition as a logical process to seeing it as a biological phenomenon.

Everything is connected to everything else. Fortunately, not all connectivity is equally dense. The nonuniformity of connectivity makes science possible. Choosing the right boundaries for a unit of analysis is a central problem in every science and the basic approach to this problem has been in place for 2,000 years. Plato advised that one should ''carve nature at its joints'' (Phaedrus 265d–266a). By this, Plato meant that

Correspondence should be sent to Edwin Hutchins, Department of Cognitive Science, University of California San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0515. E-mail: ehutchins@ucsd.edu

we should place the boundaries of our units where connectivity is relatively low. To speak of cognitive ecology is to employ an obvious metaphor, that cognitive systems are in some specific way like biological systems. In particular, it points to the web of mutual dependence among the elements of an ecosystem. Bateson's (1972) *Steps to an Ecology of Mind* is an extended argument for the idea that just as a full understanding of biological organisms must include their relations to other organisms and physical conditions in their environments;[1] so, an understanding of cognitive phenomena must include a consideration of the environments in which cognitive processes develop and operate. Bateson showed how the loops that define mind extend through the body and out into the surrounding cognitive ecosystem. He reiterated Plato's advice with a cybernetic twist, urging us not to put delimiting lines where they cut important information circuits. Bateson famously illustrated this principle with a thought experiment; the case of the blind man with a stick. Bateson said,

> Suppose I am a blind man, and I use a stick. I go tap, tap, tap. Where do I start? Is my mental system bounded at the handle of the stick? Is it bounded by my skin? Does it start halfway of the tip of the stick? But these are nonsense questions. The stick is a pathway along which transforms of difference are being transmitted. The way to delineate the system is to draw the limiting line in such a way that you do not cut any of these pathways in ways which leave things inexplicable. If what you are trying to explain is a given piece of behavior, such as the locomotion of the blind man, then for this purpose, you will need the street, the stick, the man, the street, the stick, and so on, round and round. (1972:459; Form, Substance and Difference)

Bateson touched on the same topic in another essay. Speaking about a communicational world as a ''wide network of pathways of messages,'' he noted that,

> Some of these pathways happen to be located outside the physical individual, others inside; but the characteristics of the system are in no way dependent upon any boundary lines which we may superpose upon the communicational map. (1972:251; Minimal Requirements for a Theory of Schizophrenia)

Every boundary placement makes some things easy to see, and others impossible to see. The danger of putting boundaries in the wrong place is, as Bateson warned, that doing so will leave important phenomena unexplained, or worse, inexplicable. Infelicitous boundary placement can create paradoxes and problems that cannot be solved. Plato's advice is, alas, easier to state than to follow. Every theory implies a set of ontological commitments and every ontological commitment emphasizes some kinds of connections over others. What looks like low connectivity under one theory may look like a region of high connectivity to another theory. As we tend to look where our theories indicate areas of interest, by looking in particular ways, we actually make the world appear to be the kind of place that our theories can address. This is clear in the history of cognitive science. What we think cognition *is* depends on what our theoretical commitments suggest can be explained. The question facing the field is not "Which approach is true?" but "Which approach gives us the best scientific leverage?"

Early cognitive science was shaped by the tension between reductionism and holism. In the late 1950s, two very different approaches, cybernetic and information processing, focused on different images of mind.[2] Cyberneticists like Bateson were interested in information, but they emphasized the fact that the information loops that constitute mind extend through the body into the world. This view forced an acknowledgment of the roles of the body and the world in thinking. Meanwhile, advocates of an information processing approach saw the digital computer as a model of mind and sought to explain cognition by reduction to internal symbolic events. They declared the body and its perceptual and motor systems to be peripheral to central cognition.

The information processing view triumphed in North America and quickly made some difficult choices concerning its unit of analysis. Gardner (1987) points out that while everyone agreed that culture, context, history, and affect were important aspects of cognition, taking them into account made the project too difficult. These things were set aside with the intention to return to them once the project of understanding the core of cognition was well established. It was hoped that the connections between these phenomena and the central cognitive processor were sufficiently sparse that it would be safe to ignore them. Of course, a theory of cognition that excludes culture, context, history and affect will effectively exclude the study of cognitive ecology. Cognitive science is now returning to these issues. The return is made possible by a combination of advances in understandings of how brains work and increasingly powerful demonstrations of the involvement of body and world in the constitution of the human mind. It might be thought that advances in brain science would only feed the "cognition as internal operation" approach. However, as the brain is increasingly seen as a controller of a body rather than as a computer implemented in meat (Clark, 2001, 2008), the relations of brain processes to bodily interactions with an environment become more important. Sensory and motor processes are not peripheral to modern brain science.

2. By the late 1970s

As cognitive science developed, a few research traditions committed to a cognitive ecosystem as the correct unit of analysis. As I do not have space to review them all, I will describe just three of the most influential areas here.

2.1. Ecological psychology

By the time of the first meeting of the Cognitive Science Society, Gibson (1986) had already spent three decades studying psychological processes in ecological context. His publication of the first edition of *The ecological approach to visual perception* came in 1979. Gibson stressed that psychological processes could only be understood in terms of the dynamic coupling between the animal and its environment. Gibson ridiculed the notion that visual perception could be understood by imposing patterns of light and dark on the retina of an unmoving animal eye. He pointed out that perception involves action, and he tried to show how information is carried in properties of experience that are invariant under the transformations of action. ''The eye–head–brain–body system registers the invariants in the structure of ambient light'' (Gibson, 1986, p. 61). He examined the structure of the environment (but, alas, not the cultural environment). He emphasized the fact that our perceptual systems have evolved in and are tuned to environments that offer a certain limited set of invariants. Gibson was extremely ambitious and *very* confrontational. He taunted his colleagues, saying of information processing approach to psychology, ''It will not do, and the approach should be abandoned'' (Gibson, 1986, p. 238).

2.2. *Ecology of mind*

I have already mentioned Gregory Bateson. In addition to writing a theoretical manifesto in *Steps to an Ecology of Mind*, Bateson was a key player in one of the most ambitious (and least known!) projects in the history of social science. The anthropologist, Bateson, joined a team that included the linguists McQuown and Hockett, facial expression and body language expert Birdwhistell, and psychotherapist Brosin in an attempt to document and analyze a brief stretch of interaction in a psychiatric interview. The project resulted in a report titled *The Natural History of an Interview* (McQuown, Bateson, Birdwhistell, Brosin, & Hockett, 1971). This five-volume 1,500-page manuscript consisted of one volume of discussion and four volumes of painstaking behavioral coding. The variety of expertise brought to bear reveals the researchers' understanding that human interaction is a profoundly multimodal and heterogeneous system. Their principal finding was that ''Nothing never happens.''[3] This observation was meant to highlight the fact that in culturally constructed social interactions even refraining from all action is a meaningful behavior. The project addressed many methodological problems that remain unsolved today. For example, how can multiple simultaneously relevant and interacting aspects of a complex stream of behavior be recorded and coded? They struggled with a theoretical problem; how are the patterns in all of these aspects of behavior related to one another? The project was 40 years ahead of time and technology.

The key ideas of the cybernetic approach to cognition were also part of the foundation of another influential line of research. The concept of autopoeisis as developed by Maturana and Varela (1987) describes the self-organizing processes by which organisms maintain themselves through coupling to their environments.

2.3. *Cultural-historical activity theory*

As the name implies, this approach grants culture and history central roles as theoretical constructs. Rather than setting aside culture, context, history, and affect, this approach holds that human thought develops in cultural context, shaped by historically contingent cultural practices. According to Vygotsky (1978), in individual ontogenesis, all higher level psychological processes appear twice. They appear first as interpsychological process; a child participates with others in cultural practices and in that context enacts a shared psychological processes. With repeated experience, the child may ''internalize'' the interpsychological processes which then become intrapsychological process. Because of its ties to Marxist philosophy, cultural-historical activity theory (CHAT) attended from the outset to the roles of social, material, and institutional culture in the formation of thought. This approach developed in the Soviet Union and was made accessible to the West via several traditions. Michael Cole's use of CHAT framework, beginning with work on thinking and literacy in West Africa (Cole, Gay, Glick, & Sharp, 1971; Cole & Scribner, 1974) and continuing through his work on education in the United States (Cole, 1996) may have had the most influence on cognitive science. Others introduced activity theory concepts to the study of development and everyday cognition (Rogoff & Lave, 1984; Wertsch, 1985).

These approaches defined themselves in part by their opposition to the dominant form of cognitivism as it was articulated in the late 1970s. The fact that they opposed a historically important vision of cognitive science does not mean that they are necessarily estranged from modern cognitive science. Ecological psychology, ecology of mind, and CHAT can be seen as ancestors of a modern synthesis of cognitive ecology approaches.

3. Up to the present

The three areas described above were not entirely responsible for all of the relevant developments in cognitive ecology that followed in the 30 years since the first meeting of the Cognitive Science Society. Many strands of research and theorizing weave together. The various developments form a complex intellectual ecology of mutual influences and reactions (Goldstone & Leydesdorff, 2006).

The heirs of Gibson live on in the field of ecological psychology. This approach focuses on psychological phenomena as properties of animal–environment systems. In order to understand perception, one must understand the properties of the world to be perceived. To understand action, one must understand both the motor systems and its interactions with the world. A synergistic relationship grew up between ecological psychology and the development of the dynamical systems approach to cognition. The dynamicists emphasize that the system that matters is the brain, body, and world coupled in motion (Kelso, 1995; Port & van Gelder, 1995; Spivey, 2007; Thelen & Smith, 1994), while ecological psychologists have borrowed analysis tools from dynamical systems theory (Kugler & Turvey, 1987; Michaels & Carello, 1981). Such accounts have successfully modeled many perceptual and motor processes. However, it is not clear whether high-level cognitive processes can be captured by more of the same kind of process. The heterogeneous nature of real-world human action is a continuing challenge for dynamical system models.

Organism–environment dynamics become agent–environment interactions in embodied robotics (Beer, 2008). These efforts explore the ways that agents can take advantage of structure in the environment to do thinking without representation (Brooks, 1991). Gibson's insights that perception is a form of action provided inspiration for a part of the philosophy of embodied mind movement (Hurley, 1998; Rowlands, 2006). For these authors, perceptual experience is grounded in regularities in the relations between sensation and action. These sensorimotor contingencies always entail interactions between an organism and its environment. The catchphrase for this line of work is, ''Perception is something we do, not something that happens to us'' (Noe, 2004). These approaches view organism–environment relations in terms of coupling, coordination, emergence, and self-organization rather than the transduction of information across a barrier.

As the points of contact between organism and environment come to be seen as loci of essential processes rather than as barriers and boundaries to be crossed, the role of the body in thinking comes to the fore. These ideas are being explored in two related contemporary approaches to cognition. In North America, embodied cognition is on the rise. In Europe the enaction perspective covers similar ground but from a different intellectual background.

Embodied cognition grounds high-level conceptual processes in bodily experiences (Barsalou, this issue; Calvo & Gomila, 2008; Gibbs, 2006; Johnson, 1987; Lakoff & Nunez, 2000; Pfeifer & Bongard, 2007). One of the virtues of this approach is that emotion finds a natural connection to conceptualization through processes in the body. A subfield of embodied cognition examines the relations between gesture and thought (Goldin-Meadow, 2003; McNeill, 2000, 2005). Gesture studies highlight the coordination of talk with bodily action, demonstrating the multimodal nature of communication (Hutchins & Nomura, in press).

In Europe, the enaction perspective combines the philosophy of phenomenology (Dreyfus, 1982; Heidegger, 1962; Varela, Thompson, & Rosch, 1991) with the cybernetic approach that we saw in the ecology of mind (Bateson, 1972; Dupuy, 2000). Building on the biological concept of autopoeisis (Maturana & Varela, 1987), the enaction perspective emphasizes that environments are not pregiven but are in a fundamental sense created by the activity of the organism (Havelange, Lenay, & Stewart, 2003; Kirsh, 1995). The processes of life and those of cognition are tightly linked in this view (Thompson, 2007).

Both embodiment and enaction stress the tight relation between thought and action (Alac & Hutchins, 2004; Hutchins, 2010). Enaction shares with the dynamical systems approaches a commitment to circular rather than linear causality, self-organization, and the structural coupling of organism and environment.

Paying attention to the ways that the body and mind are coupled to the environment highlights two forms of multimodality. Interactions between persons and their environments often simultaneously engage several modalities, speech and gesture, for example. It is now clear that inside the brain as well, the causal factors that explain the patterns seen in any one modality may lie partly in the patterns of other modalities. In fact, recent work suggests that activity in various cortical areas (e.g., visual and motor cortex, or visual and auditory cortex) unfolds in a complex system of mutual causality (Gallese & Lakoff, 2005; Sporns & Zwi, 2004; Wilson, Saygin, Sereno, & Iacoboni, 2004). Neuroscientists have thus become aware of the need to expand the boundaries of the unit of analysis to consider a wider cognitive ecology. In a review of psychophysiological methods Kutas and Federmeier say, ''…the complexity problem presented by the mind–brain–body system may require new ways of thinking about the kinds of measures we use and need to use because, in fact, the mind arises in a physical system that is distributed over space and time (Kutas & Federmeier, 1998).

Activity theory with its emphasis on the social construction of thought inspired other approaches that consider the cognitive consequences of social and cultural configurations (Daniels, Cole, & Wertsch, 2007). Activity theory is the direct ancestor of the situated action perspective (Greeno & Moore, 1993; Lave, 1988; Lave & Wenger, 1991; Rogoff, 2003; Suchman, 1987). With its emphasis on the interconnections of developmental processes on all timescales (phylogenetic, cultural, ontogenetic, and microgenetic), activity theory has been put to work by educational researchers as well (Greeno, 1998; Pea, 1996).

The rise of connectionism two decades ago not only transformed theories of mental representation and processing, it also spawned a wider investigation of emergent phenomena at the supraindividual level. There is now a growing literature on computational models of social and cultural systems. The emergence of language from interactions among agents is a particularly interesting area of research (Cangelosi & Parisi, 2002; Hazlehurst & Hutchins, 1998; Hurford, Studdert-Kennedy, & Knight, 1998; Hutchins & Hazlehurst, 1995, 2002; Hutchins & Johnson, 2009).

It is clear that the cognitive properties of groups can be quite different from the cognitive properties of any individual in the group (Hutchins, 1995). The organizational principles that determine the cognitive power of groups are now a hot topic (Sunstein, 2007; Surowiecki, 2004). Barabasi (2002) describes powerful regularities that explain how patterns of connectivity can change the cognitive properties of a network. The subtitle of Barabasi's book is ''How everything is connected to everything else and what it means for science, business, and everyday life.'' Echoing the theme of this article, we once again see that while everything is connected to everything else, the patterns in the density of interconnectivity determine cognitive properties of the system whether the system is an area of a brain or a group of governmental agencies responding to a crisis.

4. The next 30 years

The boundaries of units of analysis have been expanding in many areas of cognitive science for some time, as researchers transition to units defined in terms of dynamic patterns of correlation across elements rather than in terms of the inherent properties of the elements (Mandelblit & Zachar, 1998). Of course, this is exactly the approach that was advocated by Bateson (1972). As the pursuit of cognitive phenomena leads scientists to cross the existing boundaries of units of analysis the various approaches will increasingly overlap one another. My hopeful prediction is that the reality of the rich interconnectivity of the brain, body, and world will draw the many strands described here together into a coherent approach to mind as a property of cognitive ecosystems.

One of the biggest challenges of the coming decades will be working out the implications of the fact that for humans, the ''world'' (in the now familiar ''brain–body–world'' formulation) consists of culturally constructed social and material settings. The advent of culture is, after all, the transformative event in the history of the human mind (Donald, 1991; Tomasello, 1999). The human brain and human culture have coevolved. The word *culture* here is simply a shorthand way of referring to a complex cognitive ecosystem that includes, in addition to the brain, a large number of somatic and extrasomatic processes. When we approach the question of the history of mind, the unit of analysis for mind must be the cultural/cognitive ecosystem (Deacon, 1997; Jablonka & Lamb, 2005). Cognitive scientists should ask themselves, "When will it be safe to disregard this fact? When must we attend to it? How should we attend to it?"

How will the elements of the ecology that are outside the skull ever come to have relevance to the neural processes that take place inside the skull? The convergence of approaches under the rubric of cognitive ecology is already suggesting an answer. Activity in the nervous system is linked to high-level cognitive processes by way of embodied interaction with culturally organized material and social worlds (Hutchins, 2008).

Increased attention to real-world activity will change our notions of what are the canonical instances of cognitive process and which are special cases of more general phenomena. For example, private disembodied thinking is undoubtedly an important kind of thinking, but perhaps it receives more attention than it should. This mode of thinking is common among academics and can sometimes be induced in experimental subjects, but it is relatively rare in the global cognitive ecology. It is also deceptive. Far from being free from the influences of culture, private reflection is a deeply cultural practice that draws on and is enacted in coordination with rich cultural resources. The focus of intellectual attention is already shifting to the relations among action, interaction, and conceptualization. Perception, action, and thought will be understood to be inextricably integrated, each with the others. Human cognitive activity will increasingly be seen to be profoundly situated, social, embodied, and richly multimodal. The products of interaction accumulate not only in the brain but throughout the cognitive ecology.

As the field of cognitive ecology grows and matures, we will achieve a better understanding of why cognitive processes are as they are. This will be true both in a synchronic sense in terms of the functional relationships among the elements of the contemporary cognitive ecology, and also in a diachronic sense where understanding the evolution of cognition will be recast as understanding the evolution of cognitive ecologies.

Notes

1. This point is beautifully made by Turner (2000) in his book *The Extended Organism.*
2. See (Dupuy, 2000), *The Mechanization of the Mind: On the origins of cognitive science.*
3. Well, except perhaps with respect to publication, as no publisher would take on the manuscript.

Acknowledgments

I am grateful to Larry Barsalou and two anonymous reviewers for helpful comments on an earlier draft of this paper. Funding for this research was provided by NSF award #0729013, "A multiscale framework for analyzing activity dynamics."

References

Alac, M., & Hutchins, E. (2004). I see what you are saying: Action as cognition in fMRI brain mapping practice. *Journal of Cognition and Culture*, *4*(3), 629–661.

Barabasi, A.-L. (2002). *Linked, the new science of networks*. Cambridge, MA: Perseus Publishing.

Barsalou, L. (this issue). Grounded cognition. *Topics in Cognitive Science*, In press.

Bateson, G. (1972). *Steps to an ecology of mind*. New York: Balentine Books.

Beer, R. (2008). The dynamics of brain–body–environment systems: A status report. In P. Calvo & A. Gomila (Eds.), *Handbook of cognitive science: An embodied approach* (pp. 99–120). San Diego, CA: Elsevier.

Brooks, R. (1991). Intelligence without representation. *Artificial Intelligence*, *47*, 139–159.

Calvo, P., & Gomila, T. (Eds.). (2008). *Handbook of cognitive science: An embodied approach*. San Diego, CA: Elsevier.

Cangelosi, A., & Parisi, D. (Eds.). (2002). *Simulating the evolution of language*. London: Springer-Verlag.

Clark, A. (2001). *Mindware: An introduction to the philosophy of cognitive science*. Oxford, England: Oxford University Press.

Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. Oxford, England: Oxford University Press.

Cole, M. (1996). *Cultural psychology: A once and future discipline*. Cambridge, MA: Harvard University Press.

Cole, M., Gay, J., Glick, J., & Sharp, W. (1971). *The cultural context of learning and thinking*. New York: Basic Books.

Cole, M., & Scribner, S. (1974). *Culture and Thought: A psychological introduction*. New York: Wiley.

Daniels, H., Cole, M., & Wertsch, J. (2007). *The Cambridge companion to Vygotsky*. New York: Cambridge University Press.

Deacon, T. (1997). *The symbolic species: The co-evolution of language and the brain*. New York: W.W. Norton.

Donald, M. (1991). *Origins of the modern mind: Three steps in the evolution of culture and cognition*. Cambridge, MA: Harvard University Press.

Dreyfus, H. (Eds.). (1982). *Husserl: Intentionality and cognitive science*. Cambridge, MA: MIT Press.

Dupuy, J.-P. (2000). *The mechanization of the mind: On the origins of cognitive science* (M. B. DeBevoise, Trans.) Princeton, NJ: Princeton University Press.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology*, *22*(3), 455–479.

Gardner, H. (1987). *The mind's new science: A history of the cognitive revolution*. New York: Basic Books.

Gibbs, R. (2006). *Embodiment and cognitive science*. New York: Cambridge University Press.

Gibson, J. J. (1986). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Goldin-Meadow, S. (2003). *Hearing gesture: How our hands help us think*. Cambridge, MA: Harvard University Press.

Goldstone, R., & Leydesdorff, L. (2006). The import and export of Cognitive Science. *Cognitive Science*, *30*, 983–993.

Greeno, J. (1998). The situativity of knowing, learning, and research. *American Psychologist*, *53*(1), 5–26.

Greeno, J., & Moore, J. (1993). Situativity and symbols: Response to Vera and Simon. *Cognitive Science*, *17*, 49–59.

Havelange, V., Lenay, C., & Stewart, J. (2003). Les représentations: Mémoire externe et objets techniques. *Intellectica*, *35*, 115–131.

Hazlehurst, B., & Hutchins, E. (1998). The emergence of propositions from the coordination of talk and action in a shared world. In K. Plunkett (Ed.), *Language and Cognitive Process. (Special issue on Connectionist Approaches to Language Development)*, *13*(2/3), 373–424.

Heidegger, M. (1962). *Being and time*. New York: Harper and Row.

Hurford, J., Studdert-Kennedy, M., & Knight, C. (Eds.). (1998). *Approaches to the evolution of language: Social and cognitive bases*. New York: Cambridge University Press.

Hurley, S. (1998). *Consciousness in action*. Cambridge, MA: Harvard University Press.

Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

Hutchins, E. (2008). The role of cultural practices in the emergence of modern human intelligence. *Philosophical Transactions of the Royal Society B*, *363*, 2011–2019.

Hutchins, E. (2010). Enaction, imagination, and insight. In *Enaction: Towards a new paradigm in cognitive science* (pp. 756–798). Cambridge, MA: MIT Press.

Hutchins, E., & Hazlehurst, B. (1995). How to invent a lexicon: The development of shared symbols in interaction. In N. Gilbert & R. Conte (Eds.), *Artificial societies: The computer simulation of social life* (pp. 157–189). London: UCL Press.

Hutchins, E., & Hazlehurst, B. (2002). Auto-organization and emergence of shared language structure. In A. Cangelosi & D. Parisi (Eds.), *Simulating the evolution of language* (pp. 279–305). London: Springer-Verlag.

Hutchins, E., & Johnson, C. (2009). Modeling the emergence of language as an embodied collective cognitive activity. *Topics in Cognitive Science*, *1*, 523–546.

Hutchins, E., & Nomura, S. (in press). Collaborative construction of multmodal utterances. In C. Goodwin, J. Streek, & C. Lebaron (Eds.), *Embodied interaction: Language and body in the material world*. Hillsdale, NJ: Cambridge University Press.

Jablonka, E., & Lamb, M. (2005). *Evolution in four dimensions: Genetic, epigenetic, behavioral and symbolic variation in the history of life*. Cambridge, MA: MIT Press.

Johnson, M. (1987). *The body in the mind: The bodily basis of meaning, imagination, and reason*. Chicago: University of Chicago Press.

Kelso, S. (1995). *Dynamic patterns*. Cambridge, MA: MIT Press.

Kirsh, D. (1995). The intelligent use of space. *Artificial Intelligence*, *73*, 31–68.

Kugler, P., & Turvey, M. (1987). *Information, natural law, and the self-assembly of rhythmic movement*. Hillsdale, NJ: Erlbaum.

Kutas, M., & Federmeier, K. (1998). Minding the body. *Psychophysiology*, *35*, 135–150.

Lakoff, G., & Nunez, R. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being*. New York: Basic Books.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. New York: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Mandelblit, N., & Zachar, O. (1998). The notion of dynamic unit: Conceptual developments in cognitive science. *Cognitive Science*, *22*(2), 229–268.

Maturana, H., & Varela, F. (1987). *The tree of knowledge: Biological roots of human understanding*. Boston: New Science Library.

McNeill, D. (Ed.). (2000). *Language and gesture*. New York: Cambridge University Press.

McNeill, D. (2005). *Gesture and thought*. Chicago: University of Chicago Press.

McQuown, N., Bateson, G., Birdwhistell, R., Brosin, H., & Hockett, C. (1971). *The natural history of an interview*. Chicago: University of Chicago Library.

Michaels, C., & Carello, C. (1981). *Direct perception*. Englewood Cliffs, NJ: Prentice-Hall.

Noe, A. (2004). *Action in perception*. Cambridge, MA: MIT Press.

Pea, R. (1996). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47–87). New York: Cambridge University Press.

Pfeifer, R., & Bongard, J. (2007). *How the body shapes the way we think: A new view of intelligence*. Cambridge, MA: MIT Press.

Port, R., & van Gelder, T. (1995). *Mind as motion: Explorations in the dynamics of cognition*. Cambridge, MA: MIT Press.

Rogoff, B. (2003). *The cultural nature of human development*. New York: Oxford University Press.

Rogoff, B., & Lave, J. (1984). *Everyday cognition: Its development in social context*. Cambridge, MA: Harvard University Press.

Rowlands, M. (2006). *Body language: Representation in action*. Cambridge, MA: MIT Press.

Spivey, M. (2007). *The continuity of mind*. New York: Oxford University Press.

Sporns, O., & Zwi, D. (2004). The small world of the cerebral cortex. *Neuroinformatics*, *2*, 145–162.

Suchman, L. (1987). *Plans and situated actions: The problem of human-machine communication*. New York: Cambridge University Press.

Sunstein, C. (2007). *Infotopia: How many minds produce knowledge*. New York: Oxford University Press.

Surowiecki, J. (2004). *The wisdom of crowds: Why the many are smarter than the few and how collective wisdom shapes business, economies, societies, and nations*. New York: Doubleday.

Thelen, E., & Smith, L. (1994). *A dynamical systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.

Thompson, E. (2007). *Mind in life: Biology, phenomenology, and the sciences of mind*. Cambridge, MA: Harvard University Press.

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambridge, MA: Harvard University Press.

Turner, J. S. (2000). *The extended organism: The physiology of animal-built structures*. Cambridge, MA: Harvard University Press.

Varela, F., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

Vygotsky, L. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Wertsch, J. (1985). *Vygotsky and the social formation of mind*. Cambridge, MA: Harvard University Press.

Wilson, S., Saygin, A., Sereno, M., & Iacoboni, M. (2004). Listening to speech activates motor areas involved in speech production. *Nature Neuroscience*, *7*(7), 701–702.