The Smoke Around Mirror Neurons: Goals as Sociocultural and Emotional Organizers of Perception and Action in Learning

Mary Helen Immordino-Yang[1]

ABSTRACT—From the pragmatists to the neo-Piagetians, development has been understood to involve cycles of perception and action—the internalization of interactions with the world and the construction of skills for acting in the world. From a neurobiological standpoint, new evidence suggests that neural activities related to action and perception converge in the brain in high-level sensory association and motor planning areas that have been described as "mirror neuron areas." However, the term "mirroring" can be misleading for educators and neuroscientists alike, as it suggests a direct and largely passive internal reflection of another person's goals and actions into one's own brain. Building from my colleagues' thoughts on my earlier study of two hemispherectomized boys (M. H. Immordino-Yang, 2007, pp. 66–83; see commentaries, this issue), in this response to commentaries, I suggest a model in which the internalization of another's goals and actions happens in a culturally modulated dynamic interaction between minds and is grounded in the neuropsychological strengths and weaknesses of the learner. In this approach, learners capitalize on their strengths and preferences to internalize and construct representations of problem domains, a process that is organized by the "smoke around the mirrors"—sociocultural and emotional factors.

[1]Brain and Creativity Institute/Rossier School of Education, University of Southern California

Address correspondence to Mary Helen Immordino-Yang, Brain and Creativity Institute/Rossier School of Education, University of Southern California, 3641 Watt Way, Suite B17, Los Angeles, CA 90089-2520; e-mail: mhimmordino-yang@post.harvard.edu

Across many perspectives from the pragmatists to the neo-Piagetians, development has been analyzed in terms of cycles of perception and action—a combination of the internalization of interactions with the world and the construction of skills for acting in the world. In "A tale of two cases: Lessons for education from the study of two boys living with half their brains" (Immordino-Yang, 2007), I showed that Nico (missing his right cerebral hemisphere) and Brooke (missing his left) had compensated for basic neuropsychological skills to previously unexpected degrees and argued that the ways they had compensated revealed general principles about the active role of the learner and the organizing role of emotion and social interaction in development.[1] In this paper, building from my original argument and from those of my colleagues in their commentaries (Ablin, 2008; Christoff, 2008; Snow, 2008; van Geert & Steenbeek, 2008), I argue that the juxtaposition of Nico's and Brooke's performances provides a powerful wedge into the problem of individual differences through providing an extraordinary example of the relationship between perception and action in learning. This example leads to a tentative scheme that brings together cognitive developmental theory with recent neurobiological evidence on the functioning of mirror neuron systems in the brain, to produce pedagogically relevant insights into the nature of contextualized skill development and a deeper analysis of the functioning of mirror neuron systems in learning.

In the sections that follow, I extend the argument from my original paper to claim that Nico's and Brooke's patterns of skills for prosody (the affective intonation or melody of speech) can be interpreted as complementary examples of the relationship between perception and action in development. I argue that taking such an interpretation leads to a more differentiated view of the relationship between perception and action that begins to account for the role of neuropsychological strengths and weaknesses in creating variability between learners. Taken together with recent evidence from cognitive and affective neuroscience (Immordino-Yang & Damasio, 2007), as well as evidence from cognitive developmental theory and research, this interpretation points us toward a more biologically grounded, testable model of the relationship between perception and action in learning.

ACCOUNTING FOR VARIABILITY IN SKILL DEVELOPMENT: UNDERSTANDING NICO'S AND BROOKE'S BEHAVIOR IN TERMS OF PERCEPTION, ACTION, AND THEIR CONVERGENCE

There is a long tradition in educational theory of analyzing development in terms of dynamic feedback loops between action and perception, starting with the pragmatists of the early 20th century, including figures such as Dewey and Pierce (see Hartshorne & Weiss, 1965; Hickman & Alexander, 1998), and continuing into modern thinking in cognitive science and developmental psychology (e.g., Bruner, 1973; Case, 1998; Fischer & Immordino-Yang, 2002). Piaget described this well with his concepts of "assimilation," in which a learner acts in the world based on his or her current understanding, and "accommodation," in which feedback from these interactions is incorporated into the learner's understanding of how the world works (Piaget, 1937/1954). In these constructivist approaches, learning does not involve passively receiving information imparted by a teacher. Instead, learning is an active, iterative process in which a student acts on and perceives the environment, in part through engaging in social interactions with other people.

Many modern views of development build on these ideas. For example, Fischer and his colleagues posit that the most basic elements of cognitive development, present at birth, are reflexes (Fischer & Bidell, 2006). Just as chemical elements are the smallest units of a substance that retain its properties, in Fischer's neo-Piagetian view, reflexes are the smallest coherent units of behavior and thought. Importantly, these reflexes function at the nexus of perception and action. When a reflex is triggered, a baby first perceives a stimulus that has the capability to produce a particular action and the action automatically ensues. With development and experience, this cyclic process of moving between perception and action, in dynamic feedback loops with the world, becomes the substrate for increasingly complex behavior and thought. Actions and perceptions, and eventually thoughts about these actions and perceptions, are actively coordinated into functional skills for thinking, feeling, and acting in the social and physical world.

Moving back to the evidence described above, Nico and Brooke's recoveries show us one example of how perception (instantiated in the brain as sensory processing) and action (instantiated in the brain as motor planning and representation) are grounded in neuropsychological strengths and weaknesses. That is, it could be argued that both boys are compensating for their neurological deficits by constructing skills that connect their perception of prosody as pitch contours with their motor plans for producing prosody. Because each boy is missing half of the neural hardware normally used for perception and motoric representation, the patterns of skills the boys create reflect the strengths of their perceptual and motoric origins, as well as the social and emotional goals of the skill (Immordino-Yang, 2007). In this interpretation, each boy's motor plans for producing prosody are mapped onto his perceptions of others' prosody with the goal of creating and understanding socially relevant speech cues. Together, these boys demonstrate that neuropsychological profiles of strengths and weaknesses in perception and action can vary quite a lot, yet if the social and emotional features of the context are well suited to the construction of meaningful, goal-directed skills, perception and action can come together, and the behavioral outcome can be surprisingly normative.

Brooke and Nico demonstrate this quite nicely in their discussions about prosody in sarcastic and sincere contexts. For example, Brooke talks extensively about how he would feel or talk in different social contexts and with different prosodic intents. With each prosodic possibility that he generates (via motor planning), he builds a connection to the sound of the speech he would create (via perceptual representations) and relates this to an associated social goal (e.g., how to talk appropriately to one's grandmother). Nico, on the other hand, maps his perception and motoric representation of prosody in the most efficient way possible to accomplish the goal of speaking normally and understanding social situations, skills that by conventional neurological wisdom he should not have. For him, perception and action come together to produce a set of features for categorizing pitch in the speech he hears and produces.

Interestingly, evidence from cognitive neuroscience suggests that the iterative, recursive process of bringing together perceptual and motoric representations in the brain forms a major component of learning and memory, as well as a basic mechanism for social interaction and learning. In the next section, I briefly outline this line of thinking and draw tentative connections to processes of skill development as they have been described in the developmental literature.

NEUROLOGICAL CONVERGENCE: NETWORKS THAT SUPPORT SKILL DEVELOPMENT

As described above, dynamic cycles between perception and action have been understood for decades to be a major organizing force in development. Here, I will begin to integrate new information from cognitive neuroscience with this framework, with the aim of proposing a direction of thinking that may advance our understanding of the biological grounding of skill development, including in social contexts.

Specifically, the last decade marks the identification of a possibly new type of system in the brain, dubbed "mirror systems" by their discoverers (DiPellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fogassi, & Gallese, 2001; Umiltà et al., 2001). The neural architecture that enables these systems was posited to exist by Damasio in his 1989 exposition of "convergence zones"[2] (Damasio, 1989; Damasio, & Damasio, 1993). Damasio argued that meaningful learning and memory for coherent, contextualized experiences would be physically impossible without a neurological mechanism for the interface of sensory and motor systems in the brain. He dubbed such systems convergence zones[3] and posited that association cortices in the brain were likely the neurological substrates for such processing. Deducing the functioning of particular association areas from the patterns of deficits associated with brain damage in different locations, Damasio and his colleagues (see Damasio, 1989, for a review) described selective deficits in various domains, for example, in language, social functioning, and visual processing that, when probed, revealed a neurological system for learning and behaving in which perceptions (either from the environment or from the recall) and actions (either in the environment or in the mind) are built into increasingly complex amodal representations, in effect memories of one's experiences. These memories, each the product of convergence between perception and action at increasingly complex levels, are embodied in recursive, looping networks that project both forward toward convergence zones and back again into perceptual and motor areas. These networks can be iteratively reactivated and modified as the situation requires, resulting in the construction of coherent, goal-directed thoughts, plans, and behaviors. Notably, a person need not directly experience in the environment every action or perception; instead, he can mentally conjure these experiences based on memory or imagination. Of necessity, these internally derived activations in the form of memories or imaginings will reflect the biological predispositions and previous subjective experiences of the learner.

Although not described as such at the time, I would argue that this iterative reconstruction of perceptual and motoric experiences is, in essence, the basic process that allows the development and calling up of contextually relevant skills. As a learner interacts with the social and physical environment, either by mentally conjuring it or by directly experiencing it, she engages dynamic feedback loops between what she perceives and how she acts, thinks, and feels. As she moves through dynamic cycles of perception and action, actual, recalled, or imagined, she creates skills that reflect three general dimensions: one that is perceptual, one that is motoric, and one that is goal directed and results from the convergence of the other two. Because she is acting and perceiving in a social and physical world, the goals she constructs will reflect the social, cultural, and physical constraints of the environment.

One important feature of skill development is that children and adults construct their own skills, but they do so in part by learning from other people. Intriguingly, as alluded to above, the past decade marks major discoveries about the biological mechanisms by which this may happen. In particular, this work collectively suggests that the same association areas that are active when one's own perceptual and motoric representations converge are active, albeit to a lesser degree, when we witness this convergence process for another person, providing that we implicitly understand the context and goals of the other person's actions. It has been hypothesized that this "mirror" property may form the most basic biological mechanism by which we internalize and learn from another person's thoughts and actions (for a discussion, see Oberman & Ramachandran, 2007).[4]

Although the functioning of mirror systems in the brain continues to be actively investigated, this research is revealing some of the mechanisms that permit people to learn from social contexts (Wood, Glynn, Phillips, & Hauser, 2007; Oberman, Pineda, & Ramachandran, 2007). Although in no way do mirror neuron systems tell the whole story of the neurological processing of social interaction, they do provide a necessary mechanism for the translation of another person's perceived, goal-directed action into the neurological motor plans that would produce it in one's own body. In this way, mirror systems enable at the most basic level the internalization of the goals of another's actions, including actions that belie emotional states, onto the substrate of one's own self. As Frith and others have described (Frith & Frith, 2006), this process is critical for imitation or other social learning to take place, as well as for empathy, in essence the vicarious experience of another's emotional state. In this way, convergence zones form a basic neurological mechanism for learning, by enabling the convergence of action and perception in context, either directly or vicariously experienced. Because convergence zones are connected bidirectionally to perceptual and motoric networks, I propose that the recursive looping of activations between these three types of networks ultimately gives rise to the development of goal-directed skills.

One important aspect of motor planning in the brain that is critical to understanding perceptuomotor convergence lies in the assumption that behavior is goal directed. Motor plans are not randomly generated; instead, they reflect the cognitive and emotional goals, knowledge, and context of the person creating them. Because of this, mirror systems seem likely to be recruited only when we understand the implicit goal of another's actions. For a simple example from nonhuman primates, Kohler et al. (2002) showed that when monkeys that had been allowed to play with rip pieces of paper listen to the sound of paper being ripped, the monkeys' brains show an increase in activity in mirror areas. This is presumed to be because the monkeys understand the meaning or goal of the sound they have perceived and have translated this goal into its accompanying motor plan. By contrast, monkeys who have never played with paper would show no increase in mirror neuron activity when they perceive evidence of that particular action, for example, the sound of paper being ripped, presumably because there would be no convergence happening. These monkeys would not know about the relationship between the action of ripping paper and the perception of this process; to them, the sound of paper ripping would be akin to white noise.

For a complementary example, Umiltà et al. (2001) showed that monkeys show increases in mirror activity when watching experimenters undertake goal-directed actions. Whether the culminating goal-directed action is completed in or out of view, if the monkey infers the goal-directed nature of the movement, the appropriate mirror systems will respond and convergence between perceptual and motoric representations will take place. However, when the action is pantomimed, such that there is no apparent goal, the monkeys show no increase in mirror neuron activity. Interestingly, this result differs between monkeys and people—because people do appreciate the implicit goal in pantomimed actions, human subjects have been shown to activate mirror areas when observing pantomimes of goal-directed actions, for example, opening a bottle, but not when observing non–goal directed actions (Grèzes, Costes, & Decety, 1998). Although the research with people is not yet conclusive, there is increasing evidence that if people do not recognize that another's actions are goal directed, mirror systems will not be activated and convergence will not take place.

Overall, I am proposing an integrative model in which the cognitive constructs of perception and action are operationalized neurologically in sensory and motor processing, respectively. Sensory and motor processing then converge in the brain, a process that involves networks of association areas referred to by Damasio (1989) as convergence zones. The iterative and dynamic process of convergence results in the formation of goal-directed actions and thoughts, by connecting actions and perceptions, including mental actions and simulated perceptions, to memory for the social and physical context. This process leads to the development of skills, in essence flexible repertoires of goal directed, contextually relevant representations built from the convergence of actions and perceptions. These skills can be experienced directly or vicariously, thanks to the mirror properties of some convergence zones, enabling us to learn from another person's goal-directed action, provided this action makes sense within our developmental and cultural frame of knowledge.

THE SMOKE AROUND THE MIRRORS: ACTION AND PERCEPTION IN SOCIOCULTURAL CONTEXT AND IMPLICATIONS FOR PEDAGOGY

In the original papers outlining the discovery and functioning of brain mechanisms for comprehension of others' actions. Rizzolatti and his colleagues (DiPellegrino et al., 1992; Gallese et al., 1996; Rizzolatti et al., 2001; Umiltà et al., 2001) dubbed their discovery "mirror neuron systems." Although this term captures one essential feature of the functionality of some neurological association areas, I would argue that the term "mirroring" could be misleading for educators and neuroscientists alike, as it suggests a direct and largely passive internal transposition of another person's goals and actions into one's own brain. The job of mirrors is to reflect what is before them, and mirror systems in the brain, as they have been described, reflect the actions and goals of another person. In this sense, mirroring suggests a direct internalization of another's actions, emotions, and goals, which are then automatically experienced in parallel in the onlooker. But although this internalization of another's situation can be automatic, the representation of another's situation is constructed and experienced on one's own self in accordance with cognitive and emotional preferences, memory, cultural knowledge, and neuropsychological predispositions—the "smoke" around the mirrors.

Returning to my original argument, analyzing Nico's and Brooke's recoveries in light of neurobiological evidence for the convergence of perception and action in light of socioculturally relevant goals gives us new, testable insights into the development of skills and into the role of neuropsychological strengths and weaknesses in constraining development. In interpreting the evidence in this way, we come closer to accomplishing the goals set out in my original article (Immordino-Yang, 2007), including shedding some light on the relationship between brain and experience in development, the organizing role of emotion in this process, and new insights into how students' unique profiles of strengths and weaknesses may play out in learning contexts.

In particular, analyzing these boys' development in this way helps us to understand that the convergence between perception and action in the brain is a socially and emotionally organized process that involves what van Geert and Steenbeek described as "interacting creative minds" (van Geert & Steenbeek, 2008, p. xx). For minds to creatively interact, some mechanism for the dynamic transference of goals between people must exist. Further, for the goals to be recognized by both people involved in an interaction, they must be understood as sensible in the sociocultural context of the interaction. I refer to this as the "smoke around the mirrors"—knowledge about the sociocultural context and its role in organizing the convergence of perception and action to produce goal-directed skills. Commensurate with van Geert and Steenbeek's model, artful and effective teaching and learning depend on the efficient, appropriate, and flexible modeling of skills and their implicit goals to maximize the efficacy with which skills are shared within classroom contexts. Of course, as van Geert and Steenbeek describe, effective education is also dependent on the productive nature of the goals—for example, students whose main goal is to avoid learning math will not build competent math skills.

Further, this approach sheds light on the neuropsychological sources of variability in students' learning. It suggests that to learn from a teacher, each student must perceive the lesson and, via neurological convergence, represent what they perceive in terms of motor plans and goals. Therefore, just as we saw for Nico and Brooke, sources of variability will include each student's unique profile of strengths and weaknesses in mechanisms of perception as well as action (motor planning). In addition, because these goals are conceived in a sociocultural context that brings to bear a student's previous experiences and preferences, a third source of variability will be in the construction and interpretation of the goals themselves. For example, the common goal of Nico's and Brooke's compensatory processing is to use and understand affective prosody as a window into participation in social interactions. However, the skills that subserved this goal for each boy were different and reflected each boy's neurological profile of strengths and weaknesses in perception and motor planning for speech.

In terms of implications for mainstream classrooms, Ablin (2008) related this process to principles of lesson design and student–teacher interaction with his description of skill development as one of individualized problem construction. That is, rather than encouraging students to try to directly internalize a teachers' goals, he suggests that we provide students with opportunities to engage with the teacher's goals indirectly through a process of active problem construction. As he describes, incorporating this pedagogical method into lessons may facilitate each student in developing skills that will best capitalize on his or her own abilities and preferences.

Thinking about skill development in this way, we see that a student's profile of neurological strengths and weaknesses, while constraining the particulars of what Snow called "procedures" of learning (Snow, 2008), does not independently determine the behavioral outcome. Neural strengths and weaknesses cannot be the only factors that predict a student's outcome because, as we have seen, the outcome is influenced as well by the sociocultural knowledge context in which convergence happens and the (often) implicit goals of the skill development. Borrowing from van Geert and Steenbeek's view, the outcomes of learning are the product of a dynamic interaction between perceptual and motoric representations, either directly or empathically experienced or simulated, organized by a person's socioculturally relevant goals and history. For example, it could be said that Nico and Brooke achieved their good prosodic skills in part because they *wanted* to and in part because their supportive social environments encouraged them to. (See van Geert and Steenbeek, for a discussion of the role of "wants" and "cans" in relation to these boys' achievements.)

As Snow notes, this has important implications for pedagogy and assessment, as educators and policy makers often focus too heavily on standardizing the means to achieving a particular skill, be it long division in math or phonological processing in reading, without providing adequate support for learners to achieve similar skills by different means (what Christoff (2008) referred to in a neuropsychological context as "solution-oriented" learning). As Nico and Brooke demonstrate, the interplay between each students' perceptual and motoric representations can lead to outcomes in behaviors and skills via convergence that are similar across students even while the nature of students' underlying representations and skills can be very different. As Snow describes, it is therefore important that pedagogical and assessment tools be designed to test students' functional abilities, without penalizing them for constructing knowledge in disparate ways. Further, building from Snow's and Christoff's commentaries, I suggest that designs for lessons and learning experiences should be mindful of each aspect of the process of constructing goal-directed skills, perhaps specifically addressing the range of ways that students may be perceiving, acting upon, and socioculturally understanding a domain of knowledge. Indeed, the most successful educational tools and assessments already incorporate these considerations into their design, allowing many different pathways to similar ends. Some examples include Universal Design for Learning (Rose & Meyer, 2006) and Singer's model of math teaching (Singer, 2007). However, a further refinement to the understanding of students' alternate pathways would involve explicit consideration of the perceptual, motoric, and socioemotional aspects of the skill to be constructed, examined in light of the learners' own goals.

In conclusion, in this response to commentaries, I bring together the insights of my colleagues with neurobiological evidence and the interpretations suggested in my original paper to propose a more biologically grounded approach to skill development. In this approach, processing for perception and action converge in the brain, in a way that is socially and emotionally organized and that involves a dynamic interplay between minds. Social and emotional reactions and desires, as well as cultural knowledge, modulate this convergence, resulting in the development of skills that are goal directed, influenced by the social context, and reflect the perceptual and motoric strengths and weaknesses of the learner. This approach suggests pedagogically relevant insights into the sources of variability between learners, as well as implications for more effective teaching and assessment of varied learners.

Acknowledgments—The author is deeply grateful to all those who made this work possible, especially Nico, Brooke and their families, Kurt Fischer, Catherine Snow, Catherine Ayoub, Antonio Damasio, Hanna Damasio, Antonio Battro, Jane Holmes-Bernstein, Michael Connell, David Daniel, and numerous research assistants, particularly Lucia Maldonado. For engaging me in this dialog, warm thanks go as well to Jason Ablin, Kalina Christoff, Catherine Snow, Henderien Steenbeek, and Paul van Geert. This work was supported by the Spencer Foundation, the American Association of University Women Educational Foundation, the Harvard University Mind Brain and Behavior Initiative, and an anonymous grant.

NOTES

1 As described in my original article, Nico and Brooke each underwent hemispherectomy, a surgical procedure in which one cortical hemisphere of the brain is removed or functionally disconnected to control severe and intractable epileptic seizures.

Both boys and their families asked that they be identified by their real first names.

2 Antecedents of the idea that Damasio explicated more fully can be found in earlier writings, for example in Donald Hebb's (1949) *Organization of behavior*. New York: Wiley. Importantly, though, while Damasio's convergence zones make use of Hebbian learning, they function in two directions. The connectivity of these networks brings together neural signals about simpler pieces of information to create the neural substrates of more complex mental representations. Once bound together, the activity in convergence zones also feeds back, retroactivating simpler perceptual and motoric units upstream and thereby reconstituting the original separate set of perceptual and motoric activations. It is this looping, recursive quality that allows these networks to support skill development as I am describing it.

3 Note that Damasio laid out a hierarchical neural architecture with early, modal cortices feeding into and receiving projections from "local" convergence zones, which in turn reciprocally connect to "non-local" convergence zones, located in higher-order association cortices. The mirror systems I am describing correspond to "non-local" convergence zones, which are amodal and carry out the lowest level of processing in which sensory and motor representations are brought together. While not all convergence at this level involves both sensory and motor components, I would argue that the goal-directed processing that is relevant to my argument about skill development does involve both of these aspects.

4 It is important to note that convergence zones with mirror properties have been discovered in characteristic anterior (frontal) and posterior (mainly inferior parietal) locations in the brain. The mirror systems that I am describing as sensitive to the goals of actions are generally the frontal systems. Although the parietal systems are mainly perceptual, the frontal systems are mainly motoric and are engaged therefore when perception and action converge to make goal-directed motor plans and representations.

REFERENCES

Ablin, J. L. (2008). Learning as problem design versus problem solving: Making the connection between cognitive neuroscience research and educational practice. *Mind, Brain, and Education*, *2*(2), 52–54.

Bruner, J. S. (1973). Organization of early skilled action. *Child Development*, *44*, 1–11.

Case, R. (1998). The development of conceptual structures. In D. Kuhn & R. Seigler (Eds.), *The handbook of child psychology, Vol. 2: Cognition, perception, and language* (5th ed., *Vol. 2*, pp. 745–800). New York: Wiley.

Christoff, K. (2008). Applying neuroscientific findings to education: The good, the tough and the hopeful. *Mind, Brain, and Education*, *2*(2), 55–58.

Damasio, A. R. (1989). Time-locked multiregional retroactivation: A systems-level proposal for the neural substrates of recall and recognition. *Cognition*, *33*, 25–62.

Damasio, A. R., & Damasio, H. (1993). Cortical systems underlying knowledge retrieval: Evidence from human lesion studies. In T. A. Poggio & D. A. Glaser (Eds.), *Exploring brain functions: Models in neuroscience* (pp. 233–248). New York: Wiley.

DiPellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research*, *91*, 176–180.

Fischer, K. W., & Bidell, T. (2006). Dynamic development of action and thought. In W. Damon & R. Lerner (Eds.), *Handbook of child psychology, Vol. 1: Theoretical models of human development* (6th ed., pp. 313–399). Hoboken, NJ: Wiley.

Fischer, K. W., & Immordino-Yang, M. H. (2002). Cognitive development and education: From dynamic general structure to specific learning and teaching. In E. Lagemann (Ed.), *Traditions of scholarship in education*. Chicago: Spencer Foundation.

Frith, C. D., & Frith, U. (2006). The neural basis of mentalizing. *Neuron*, *50*, 531–534.

Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain*, *119*, 593–609.

Grèzes, J., Costes, N., & Decety, J. (1998). Top down effect of strategy on the perception of human biological motion: A PET investigation. *Cognitive Neuropsychology*, *15*, 553–582.

Hartshorne, C., & Weiss, P. (Eds.). (1965). *Collected papers of Charles Sanders Peirce, Volumes I and II: Principles of philosophy and elements of logic*. Cambridge, MA: Harvard University Press.

Hebb, D. O. (1949) *Organization of behavior*. New York: Wiley.

Hickman, L., & Alexander, T. (Eds.). (1998). *The essential Dewey: Volumes 1 and 2*. Bloomington, IN: Indiana University Press.

Immordino-Yang, M. H. (2007). A tale of two cases: Lessons for education from the study of two boys living with half their brains. *Mind, Brain, and Education*, *1*, 66–83.

Immordino-Yang, M. H., & Damasio, A. R. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. *Mind, Brain, and Education*, *1*, 3–10.

Kohler, E., Keysers, C., Umiltà, M. A., Fogassi, L., Gallese, V., & Rizzolatti, G. (2002). The smoke around mirror neurons: Action representation in mirror neurons. *Science*, *297*, 846–848.

Oberman, L. M., Pineda, J. A., & Ramachandran, V. S. (2007). The human mirror neuron system: A link between action observation and social skills. *Social, Cognitive and Affective Neuroscience*, *2(1)*, 62–66.

Oberman, L. M., & Ramachandran, V. S. (2007). The simulating social mind: The role of the mirror neuron system and simulation in the social and communicative deficits of autism spectrum disorders. *Psychological Bulletin*, *133*, 310–327.

Piaget, J. (1954). *The construction of reality in the child* (M. Cook, Trans.). New York: Basic Books. (Original work published 1937.)

Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, *2*, 661–670.

Rose, D. H., & Meyer, A. (Eds.). (2006). *A practical reader in universal design for learning* Cambridge, MA: Harvard Education Press.

Singer, F. M. (2007). Beyond conceptual change: Using representations to integrate domain-specific structural models in learning mathematics. *Mind, Brain, and Education*, *1*, 84–97.

Snow, C. (2008). Varied developmental trajectories: Lessons for educators. *Mind, Brain, and Education*, *2*, 59–61.

Umiltà, M. A., Kohler, E., Gallese, V., Fogassi, L., Fadiga, L., Keysers, C., et al. (2001). I know what you are doing: A neurophysiological study. *Neuron*, *31*, 155–165.

van Geert, P., & Steenbeek, H. (2008). Brains and the dynamics of “wants” and “cans” in learning. *Mind, Brain, and Education*, *2*, 62–66.

Wood, J. N., Glynn, D. D., Phillips, B. C., & Hauser, M. D. (2007). The perception of rational, goal-directed action in nonhuman primates. *Science*, *317*, 1402–1405.