IBE science of learning portal

Bridging neuroscience of consciousness and education: Part I

What are scientists discovering about consciousness and what are the implications for education?

Author/s:

Amedeo D'Angiulli
Professor, Department of Neuroscience and Neuroscience of Imagination, Cognition, and Emotion Research Lab, Carleton University, Canada

Theme/s:

Emotions and learning

This report arises from Science of Learning Fellowships funded by the International Brain Research Organization (IBRO) in partnership with the International Bureau of Education (IBE) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The IBRO/IBE-UNESCO Science of Learning Fellowship aims to support and translate key neuroscience research on learning and the brain to educators, policy makers, and governments.

Executive summary

- Consciousness involves conditions that can be observed by a third-person in our behaviors: wakefulness, background emotions, sustained attention, and purpose.
- Consciousness also includes the self as experience that can only be determined by the first-person perspective: what it is like to be you and how you experience the world.
- How we experience our world and changes within ourselves is represented through first-order maps, or neural patterns, of images within our mind that take many shapes as they can be represented through varying sensorimotor expressions (visual, auditory, somatic, proprioceptive, kinetic, etc.).
- The fact that we are aware of these mental images is expressed through second-order maps, or neural patterns, that adequately represents the self.
- The *protoself* takes into consideration unconscious processes that are automatic and maintain stability throughout our lifetime. In terms of the brain, the protoself involves networks that work in the background, such as the default mode network (DMN), the speech and language network, and mirror neurons network.
- The integration of the information and processes generated by these networks is the basis for the generation of consciousness. It involves global cross-talks of many areas across the brain.
- *Core consciousness* is our experience of the here and now and is largely dependent on sensory and motor areas within the brain; whereas *extended consciousness* is our understanding of the past combined with our expectation for the future and relies on memory and is augmented through language.
- There is a clear relationship between consciousness and emotions as it allows us to regulate our thoughts and feelings in the present but also in anticipation for the future, as evidenced in the mirror neurons network. Extended consciousness is the "complete" and unitary consciousness of self, as we generally know it, stretching across our autobiographical experience and time. It involves both the higher levels of consciousness and higher-order cognitive and emotional functions involved in creativity, intelligence, and plasticity. Given its adaptive powers, extended consciousness is the major achievement of human brain evolution.

Introduction

All teachers and educators are familiar with the students' question: "Why do we have to do this?" On careful inspection, this question is about students being self-conscious of their process of learning. It may be an irritating question for teachers, but it is central to having human consciousness. Really, it is a question at a higher level of abstraction (or *meta*) about the owner's knowledge. Such knowledge corresponds to the person, the "I," that experiences and understands this knowledge as his/hers. Not only do I know something, but I know that I know it. So who is the "I" who is doing all this knowing (and feeling)?

With the term **consciousness,** we identify this first-person-singular self that philosophers, psychologists, and theologians have long tried to define. That is, the knowledge that exists with us when we are awake, that abandons us when we go to sleep, and "mysteriously" reappears when we awaken. On this account, understanding *why* we learn is as central as understanding *how* we learn it; it may even be said that the two aspects are very connected. Because school activities focus primarily on conscious learning and behavior that involve inquiries about our own knowledge, an understanding of the neuroscience of consciousness will be essential to the development of credible theories of education, teaching, and learning. It will become indispensable as curricular approaches will move more and more on being individualized and personalized. How will it be possible to tailor instructional programs, strategies, and tools to each learner efficiently if we do not have any model of how individual experience works? In addition, knowledge about our own processes is not just important for learners but also for educators.

The purpose of this brief (Part I) is to give a very cursory survey of the current knowledge in one of the fastest expanding areas in neuroscience, the study of consciousness. A follow-up brief (Part II) will connect the basics of consciousness to educational practice. The implications for learning are profound, but surprisingly very few attempts have been made to create the bridge with education.

The starting point is establishing the minimal sufficient and necessary conditions—respectively, what is “enough” and what is a “must” for judging, with little margin of error, whether a human being, in our case a student or a learner in a classroom, is conscious? I will call these the *C-conditions*. I will explain how it is possible to develop the basis of making that judgment based on just what people show in their behavior. The reason this type of judgment is so important is that theoretically we could all be zombies! We might be doing things automatically without feeling anything or without self-reflection, that is, without any real consciousness. One main necessary condition to say that you are conscious right now is that you are in a state of **wakefulness**, that is, *not sleeping*. For example, you are reading words before you right now. Would that be sufficient to define all consciousness? Sometimes I surprise myself, especially when I am bored, staring at words, but not really reading or being aware of it. Suddenly I realize that I have read an entire page with no recollection of what I have read! Sound familiar? If yes, then you can understand that being simply awake or not sleeping is not a sufficient C-condition. This is supported by research examining severe impairments of consciousness. In particular, the vegetative state, a condition in which natural or traumatic brain damage to the cortex and some upper subcortical centers (upper brainstem, above the spinal cord), leaves an individual awake but unconscious.

Why would wakefulness be a necessary C-condition? Well, if you were in dreamless sleep right now, you would not see the words or ink on the page or pixels on the screen. Indeed, you would see nothing at all! Thus, there must be a switch-on state, and we can safely assume that condition corresponds to being awake. Historically, some of the most important milestones in neuroscientific discovery were associated with the identification of centers that are most responsible for wakefulness and sleep in animals and humans. These centers form the **ascending reticular activating system** (**ARAS**).

Still, that is not sufficient for a person observing you to determine that you are conscious. A second main C-condition that can be behaviorally observed from the third-person perspective is **background emotions.** These are continuous preverbal emotional signals (body movements, facial expression, posture, etc.) that show fatigue/boredom/energy, discouragement/enthusiasm, malaise or well-being, anxiety/relaxation and so forth; these allow us to presume (or to be more sensationalist) “read” the subject’s state of mind. For example, if I were looking at you and you were slouching on the chair, sighing and holding your head from falling on the table, your eyes rolling, I may safely presume that what you are reading is making you bored. This brings us to a third related C-condition: *sustained* attention.

Sustained attention refers to being focused for minutes on the situation-appropriate object/event, for example, trying to understand what the words you are reading mean. This is closely related to the final fourth C-condition, which is **purpose**, the fact that you have a plan in mind to do something (action), and you are following that plan, for example, finishing reading this brief to see which are the key concepts you may want to remember when you are done reading. I have put many things together here, but there are many different mechanisms that shift from orienting one’s attention to plan and then execute an action. Researchers have separated a variety of attention levels and functions, which spell out more precisely going from attention to action. Among the most important of these mechanisms, specifically for consciousness, are at one end **selective attention** and at the other end **executive functions**.

Selective attention is a process that does not require consciousness but feeds into it. Like a very efficient assistant, it provides consciousness with the most important things to focus on without going through every piece of information before us. Selective attention allows us to narrow our focus to what is important and ignore the rest. At the other end, the executive functions have the task of planning, evaluating, and then implementing (or not) responses and actions based on contents received from selective attention. Both ***cold*** (cognitive) and ***hot*** (emotional) executive contents enter the equation. To illustrate this concept, consider driving a car. Selective attention allows you to focus your attention on the road while ignoring what might be happening in a coffee shop on the street corner. Executive functions allow you to take in the information of what is in front of you and act, such as slowing down and stopping at a red light relying on *cold* executive contents: Red light means stop. If you are running late, you may respond to *hot* executive contents and speed up rather than slow down as the light changes from yellow to red.

All these conditions are indeed necessary for saying that someone is conscious. However, these alone are not enough. Only you can determine *what it is like* to be you. It is here that the first-person perspective comes into play. The third person observing you would need you to communicate in some way that you are conscious, indeed confirming you are in the observable C-conditions. However expressed, your communication is your subjective report of your immediate experiential awareness of: (1) aspects of the external environment: stimuli, objects, events, and scenes; (2) changes you experience in response to the environmental input. You have direct access to both environmental and somatic (coming from the body) input through mental images, or 1st-order maps: these are neural patterns standing in for objects/events and representing changes of the organism or protoself (Damasio, 2000, 2010). These images are sensorimotor modality-specific (visual, auditory, somatic, proprioceptive, kinetic, etc.), meaning they can be expressed and experienced in a number of different ways. They are also multiple and associated in an integrated system (associative and semantic memory systems). Although they are reported subjectively, they can be made objective by proxy, that is, they can be identified by an observable behavior or a response that occurs with having them. For example, I can cue you to imagine your mother's face and then, using electroencephalography (EEG), determine precisely when that occurred by examining your brain activity. We will see that this has key implications for learners and educators.

The next step in conscious awareness is that you have a *Self*. This aspect of consciousness is achieved through the generation of sensorimotor neural and self-neural patterns. These describe the relationship between objects and how the individual changes in response to those objects. These higher-order descriptions are 2nd-order neural patterns (2nd-order maps) representing the knowledge that mental images of objects and mental images of how the individual changes are OWNED by you, yourself. I know this all seems quite complex, but in one simple phrase: You are the master puppeteer of yourself, and you are aware of this. This is actually very well captured in the movie *Being John Malkovich*.

According to the present framework, we can then distinguish one class of unconscious processes and two types of consciousness:

1) *Protoself* consists of the neural patterns that map every part of an organism's body onto one of the various interconnected brain areas. This mapping is necessary in all animals because the brain and body must constantly communicate with each other to maintain a continuously revised sense of what is happening internally. This collection of brain networks can run in isolation and use a continuous flow of information to manage automatically (as in autopilot) various life processes, such as circulation and respiration. The protoself maintains the stability it needs across its lifetime by operating body systems within genetically established and relatively narrow regulatory ranges. For more sophisticated functions, specifically, the allocation of the brain's energy, the protoself is supported by networks working separately from all other systems in the brain, such as the default mode network (which I will describe in much detail later).

2) *Core consciousness* is the present experience now and here, biologically simple, not dependent on types of memory or language. However, we are conscious of more than our own self. Our protoself is imprisoned within the geography of its body, but sensory/motor and related brain systems also allow a conscious organism to explore the world. A stable body thus confronts a constantly shifting and expanding external environment. So not only does a brain contain a map of its body, but a conscious brain must also have a mechanism for mapping and connecting to the external world. It can be assumed that consciousness emerges when the mapped relationship between an organism and an external object (which may be another organism) has risen to the level of a feeling of what is currently happening. Core consciousness (which we share with many animals) is thus the consciousness of the here-and-now, a nonverbal imaged running account of the objects an organism confronts in a series of successive instants as it moves through and interacts with its immediate environment. Think of being both actor and spectator in a movie within our brain (a film being a sequence of still pictures that gives the illusion of movement as they quickly flash through our brain).

3) *Extended consciousness* is the biologically complex sense of self in the lifespan, including memory for the past and anticipation of the future. It depends on memory, develops ontogenetically (i.e., growing organically throughout development), and is augmented by language. Therefore, extended consciousness is a combination of the past and the future. We may live in the present, but we have lived in the past and we will probably live in the future. Damasio suggests that organisms must have a large and complex cortex to consciously move beyond the here-and-now, to profit from past experiences and avoid potential problems. The cortex must be sufficiently large (meaning having a complex organization) to contain a vast and powerful autobiographical memory that can quickly identify the largest possible range of information relevant to a new challenge. Humans, and the great apes to a lesser extent, have such a cortex.

Intelligence emerges out of the ability to enhance and expand core consciousness in time. It allows our brain to manipulate recalled information in the mental design and analysis of potential responses. The practical applications of conscious intelligence include imagination, creativity, and conscience—which have led to language, art, science, technology, and a variety of cultural and political systems (such as the shared government of a democratic society). These are all the fundamental pillars of human nurture by transmitting knowledge from parent to child, from one generation to the next.

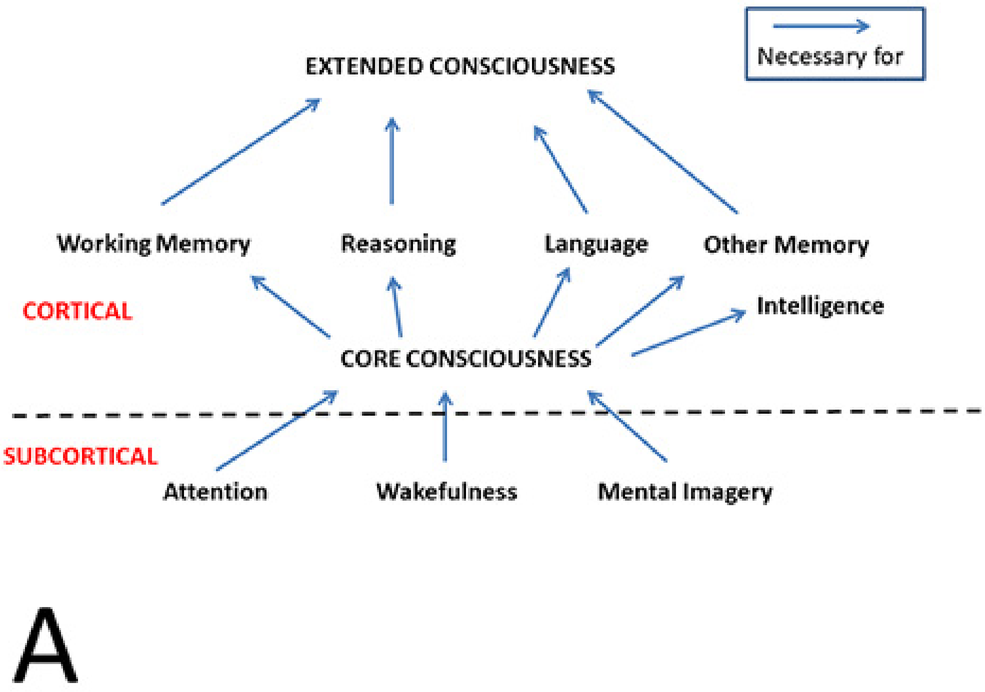

Figure 1A. Summarizes schematically the relationships between various neurocognitive aspects and the two types of consciousness as well as the neuroanatomical and functional level at which they seem to be occurring.

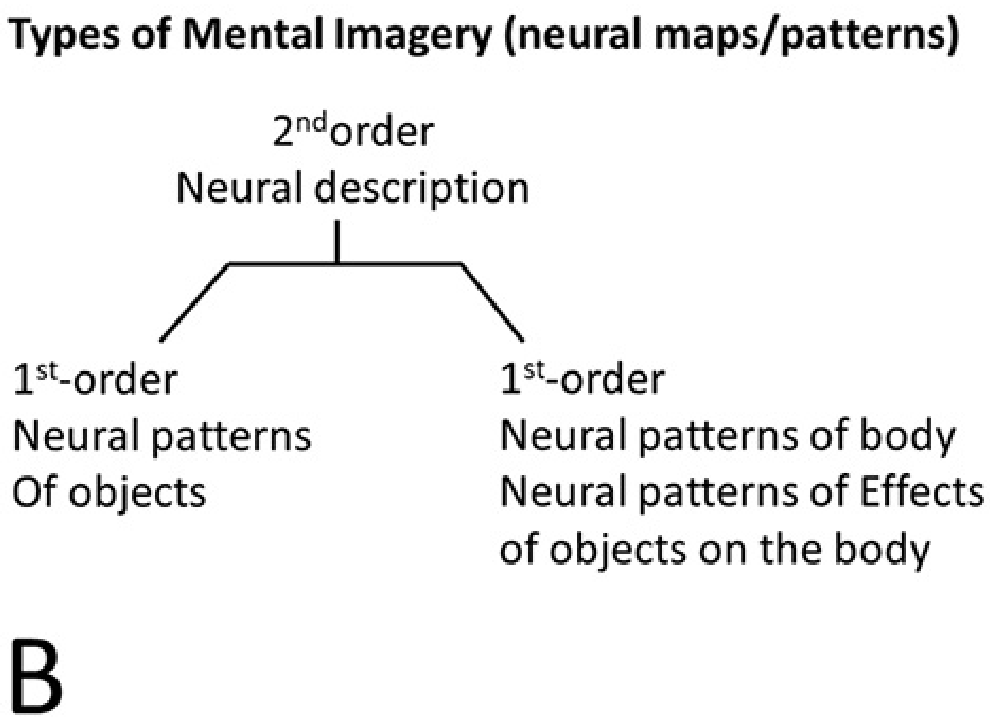

Figure 1B. Also gives a schematic description of the relationship between the levels of maps/neural patterns/images involved as contents in all those processes and dynamics. Although there might be differences in theories regarding relatively small details and technicalities, the model presented here unifies the mainstream view in the neuroscience of consciousness. The synthesis presented here is largely borrowed from Damasio's theory.

Four important corollary aspects define the relationships observed in Figure 1A:

- Core self is transient, limited to now and here interactions with objects and events
- Core consciousness depends on wakefulness and attention (at least low-level)
- Extended self (the traditional idea of self) is autobiographical
- Extended consciousness depends on core consciousness and the basic protoself

Most relevant for learning is the crucial connection between emotions and consciousness. Patients with impairment of core consciousness do not reveal emotion (by facial or body expression or vocalization). The entire range of emotions is missing in these patients. Patients with normal core consciousness but impaired extended consciousness have normal basic emotions. Therefore, the same brain territory is occupied by neural structures that are active in relation to emotion and core consciousness.

This observation has been explained with evolution. It has been proposed that consciousness started with the evolution of 2nd order maps/images and the development of a central hub-network in the brain (see Figure 1B). Subsequently, it progressed in increased complexity and richness (i.e., extended consciousness) as the central hub-network became more and more widely linked and interconnected to all other structures. There seems to be an advantage in the overlap between consciousness and homeostatic functions (body state regulation) and neural local proximity of all these centers. Consciousness may be an extension of automatic basic homeostasis for flexibility and planning in response to changes in the environment. We are not just aware of the past through memory, but in some sense, we have memory for the future (**prospective memory**). Consciousness then can be seen as a tool not only for predicting and, to some extent, controlling changes in the environment but also to regulate cognitions and emotions we experience as a self. (The interested reader is urged to read Schneider, 2014).

Locally isolated (unconscious) vs. globally shared (conscious)

We need to consider how consciousness can be reconciled with unconscious processes in complex everyday situations such as learning in school. A consensus has emerged in the field of neuroscience that has been considered a paradigm shift. The basic idea is that consciousness exists on a continuum that involves specific automatic and compact brain networks that we are born with or are acquired through much rote learning, which provide a collection of responses and processes that are mostly achieved without awareness. When two or more networks are integrated into a more complex whole system, then the system has consciousness (see Edelman & Tononi, 2000).

Speech and language processing networks

One of the best examples of local complex but independent networks involves the left-hemisphere **speech and language networks.** Evolutionarily and developmentally, it is involved primarily in our recognition of spoken language. Several fMRI (and EEG) studies show that some very specific neural networks in the left hemisphere known to respond to language are activated automatically, even if the speed or some other conditions of sound presentation prevent us from being aware of what was said (being subliminal or subthreshold). As an example, there is an automatic response to hearing your own name, even when you are unaware of it being heard above the noise in a crowd. Similarly, the same reaction has been observed in coma patients, that is, individuals that are in a level of consciousness considered a step down from vegetative state. Coma patients are not considered to have real consciousness since they are unable to respond voluntarily. However, the activity of these networks is considered to operate as islands of brain function in the sense that they are *locally isolated*.

Contrast this mode with the one revealed by fMRI (and EEG) studies when we report we are fully aware that what was said was our name; the latter shows correlated activity of many areas, *globally* across the brain. The same is also observed in vegetative state patients that recover cognitive functions. As mentioned earlier, what may be considered a paradigm shift is that in the last decade neuroscientists have begun to consider that patches of isolated functioning may be automatic and isolated, even if many of them occur simultaneously. However, critically they do not produce something that we can deliberately control, examine explicitly, or manipulate mentally. For this property to occur—that is, consciousness—the information embedded in isolated neural processes must be cross-referenced and integrated across the brain involving a global cross-talk of many areas (see Deahene, 2014) and unifying maps and neural representations of environment and body within the frame of reference of one person. Simply put, the whole is greater than the sum of its parts.

Another example of the automatic isolated network is a concept which spurred out of fMRI research findings, which proposes that the map detailing all connections in the brain, referred to as the *connectome*, corresponds more or less with a large neurofunctional system in the brain, called the **default mode network (DMN)** (Raichle, 2010). The DMN is associated with an ongoing natural idling or neuronal resting state that is reflected in the autonomous (or intrinsic) continuous activity of a discrete number of networks (currently, researchers refer mainly to three neuronal networks). If we consider the brain's budget distribution in terms of energy expenditure (i.e., metabolism), there appears to be a relationship between the distribution of conscious and unconscious processes. While in its resting idling state, the brain accounts for 20% of the entire body metabolic expenditure (very energy-expensive). But this is for largely unconscious functions; additionally, less than 5% of the brain budget is allocated to energy expenditures that are related to tasks that involve cognitive and emotional resources and are mainly under conscious awareness. It would seem that, although small, the extra expenditure required to involve our awareness stretches the brain's budget, and so its use is justified only if we really need it. It may be for this reason that learners may be reluctant to engage in tasks for which there is no reward or for which they do not know the "why."

Consciousness can, then, be conceived as the tip of the iceberg, supported by vast structural and functional "underground" unconscious machinery, which consumes most of the system's resources. This is the foundational idea behind one of the current theoretical "big picture" frameworks in consciousness science referred to as the **connectome**. The backbone of consciousness is probably made up of extensive underground networks defining relationships among brain areas. Picture the brain as a theatre production: There is the main performance, and yet, behind the curtains, there is the production crew, the costume designer, the director, the sound engineers, and many other "networks" working simultaneously in the background to ensure that the show runs smoothly.

At the same time, many researchers agree that functional connectivity, the cross-talk, during consciousness involves global sharing of information across the brain which broadcasts the end-products of the initial unconscious steps to various hubs which enable decision-making, for example, for taking an action or evaluating one's own state (e.g., emotional). However, the broadcast information does not have "infinite size," that is, we cannot be aware of all the things going on or let alone many things at one time. We can still only be aware of single images, thoughts or ideas, or chunks of information at one moment; we can be conscious of one thing at a time. The generally accepted hypothesis is that attention and other mechanisms engage in a competition contest of recognition. They search through all available pieces of information and then select the most important information for the current situation we are in. Therefore, it is very important to keep in mind that the contents of perception and attention are very different in how intense or vivid they appear when they become conscious. Consciousness is not simply an "add on," it is an amplification and an extension of what is "perceptually possible" at a given moment. In many respects, it is like a knob on a stereo used to pump up the color or the volume (within the possible maximum) in our minds.

Mirror neuron system

Another instance of an automatic isolated system is a class of neurons in the premotor area that fire (or react) in preparation for upcoming movements but, more critically, also when we observe someone else carrying out that action (Rizzolatti, Fogassi & Gallese, 2006). Common brain regions thus process both the perception and production of a movement. Therefore, this class of neurons fire at an unconscious level. The infant's observation of her parent's projecting tongue fires the premotor neurons representing her tongue. This priming activates the related motor cortex neurons that project her tongue out in mimicry. Have you ever tried to stifle a yawn in response to seeing someone else yawn? This is another prime example of this mimicking phenomenon. However, mirror neurons will not fire at the mere observation of a hand or mouth—but rather when carrying out a purposeful goal-directed action. Further, they will respond to a hand but not a tool that is grasping or moving an object (since body parts, not tools, are represented in our motor/premotor areas).

The mirror neuron system (MNS) may thus facilitate the generation of motor mental imagery or motor neural patterns or an higher order (see Figure 1B), that is, forms of neurocognitive activities that are grounded on but also go beyond the preliminary motor neuron simulation, priming, programming, and rehearsing that occurs in children (D'Angiulli & Schibli, 2011). When these processes are integrated, rather than being isolated, with other networks, for example, the neural networks that are responsible for emotions and language or purposive motor action, the MNS may enhance our eventual mastery of complex motor behaviors and our ability to "read" the minds of others. That is, it is by "assimilating" the actions the others do to our own mental imitations that we can make sense of what those actions mean. For example, imagining others' potential movements is an essential skill in many games in which players try to fake out opponents. Mirror neuron stimulation may also explain why so many people enjoy observing the movements of virtuoso athletes, dancers, and musicians. It allows us to mentally represent actions we cannot physically mimic. Note the related active body language of former athletes as they observe a game they once played, or simply watching sports on TV. Plausibly, there seems to be a direct relationship between mirror neuron activity and our ability to imagine our own planned actions, be empathetic, and develop articulate speech. The MNS is one of the brain networks that allow us to build and share (integrate) our conscious knowledge of our and others' actions after we have acquired them by imitation. This is in part in agreement with some aspects of Jean Piaget's hypothesis of the reciprocal mechanisms of assimilation and accommodation (Piaget & Inhelder, 1966/1971; Gallese & Rochat, 2010; Gallese, Rochat, Cossu & Sinigallia, 2009; D'Angiulli & Schibli, 2011).

Now that you have a broad overview of how conscious and unconscious awareness relates to the brain and behavior, in Part II, I will link this to learning and teaching in the classroom.

Acknowledgments

I thank my wife and collaborator Kylie Schibli for help with editing, feedback, and unconditional support.

References

Damasio, A. (2010). Self Comes to Mind: Constructing the Conscious Brain. New York: Pantheon.

Damasio, A. (2000). The Feeling of What Happens: Body and Emotion in the Making of Consciousness. New York: Harcourt Brace.

D'Angiulli, A., & Schibli, K. (2011). Mirror neurons and visuo-motor imagery in children: A meta-analysis of Piaget and Inhelder's data. *Imagination, Cognition & Personality, 31*(1-2), 129-143.

Deahene, S. (2014). Consciousness and the Brain. New York, NY: Viking.

Edelman, G. & Tononi, G. (2000). A Universe of Consciousness: How Matter Becomes Imagination. New York: Basic Books.

Gallese, V., & Rochat, M. (2010). Motor cognition: Role of the motor system in the phylogeny and ontogeny of social cognition and its relevance for the understanding of autism. In P. D. Zelazo, M. Chandler, & E. Crone (Eds.), *Developmental social cognitive neuroscience* (pp. 13-41). New York: Psychology Press.

Gallese, V., Rochat, M., Cossu, G., & Sinigaglia, C. (2009). Motor cognition and its role in the phylogeny and ontogeny of action understanding. *Developmental Psychology, 45*(1), 103-113.

Piaget, J., & Inhelder, B. (1966). *L'image mentale chez l'enfant: Etude sur le development des representations imagee.* Paris: Presses Universitaire Francaise. English translation: *Mental Imagery in the Child*. London, UK: Routledge & Kegan Paul (1971).

Raichle, M. (2010). The brain's dark energy. *Scientific American, 302*(3), 44–49.

Rizolatti, G., Fogassi, L., & Gallese, V. (2006). Mirrors in the mind. *Scientific American, 295*, 54 – 61. doi:10.1038/scientificamerican1106-54.

Schneider, G. E. (2014). *Brain Structure and Its Origins: in Development and in Evolution of Behavior and the Mind*. Cambridge, MA: MIT Press.