Book Review

Stanislas Dehaene, *How We Learn: Why Brains Learn Better Than Any Machine…for Now*. Viking, 2020, 319 pp., ISBN: 978-0-525-55988-7. Hardback $28.00.

Brian J. Birdsell
バードセール・ブライアン・ジョン

Hirosaki University, Japan
弘前大学

Neuroscience is an interdisciplinary science that examines the nervous system from neurons to neural circuits and investigates the biological basis for many human behaviors such as language (Kemmerer, 2014) and creativity (Abraham, 2018). Neuroscience research has also provided insight into the neural mechanisms involved with learning. Consequently, in the field of education, interest in the neurosciences has been growing in order to discover more effective ways to enhance and strengthen the process of learning among students. Thus, an increasing number of bidirectional links between these two fields have been forged leading to a new and expanding field called neuroeducation (for more information, see Ansari, de Smedt, & Grabner, 2012; Carew & Magsamen, 2010). Stanislas Dehaene is a leading neuroscientist whose previous work has focused on the neuronal basis of reading (*Reading in the Brain: The Science and Evolution of a Human Invention*, published in 2010), numerical cognition (*The Number Sense: How the Mind Creates Mathematics*, published in 2011), and consciousness (*Consciousness and the Brain: Deciphering How the Brain Codes Our Thoughts*, published in 2014). Currently he is a professor at the Collège de France in Paris and is the director of Neurospin, a research center for innovation in brain imaging.[1] His most recent book, *How We Learn: Why Brains Learn Better than any Machine…for Now* further bridges the field of neuroscience and education, as it provides both insight into the neural processes of learning, memory, and language development, as well as offering practical suggestions (what he refers to as the "four pillars") to optimize learning. In this book review, I first provide an outline of the different parts of the book and then critique some of the themes from the chapters.

Outline of the book

The book is divided into three parts. In the first part, Dehaene provides the reader a number of definitions for learning and then argues that our brains are still better at learning than any current artificial intelligent machine. One topic that Dehaene refers to throughout the book is the age-old debate between empiricism (i.e., at birth the mind is a blank slate or *tabula rasa* and human cognition develops solely through sensory and motor experiences; as in *nurture*) and innatism (i.e., at birth the mind is born with inborn structures that provide the child with knowledge and language; as in *nature*). Dehaene repeatedly aims to convince the reader that the tabula rasa argument is flatly wrong (see pp. 53, 57, 119 for a few examples) and the debate of either nature or nurture is erroneous because in

[1] See https://joliot.cea.fr/drf/joliot/en/Pages/research_entities/NeuroSpin.aspx for more information.

reality, it is both. He elaborates on the importance of both nature and nurture for the development of the brain in Part 2 of the book. The first two chapters in Part 2 describe the well-developed brain of a baby at birth and how the baby comes into this world endowed with neuronal circuits for performing a variety of cognitive tasks. The second two chapters (Chapters 5 and 6) in Part 2, on the other hand, illustrate the plasticity of the human brain and how the brain can actually recycle neuronal structure to perform new functions, which is essential for learning new knowledge like mathematics or reading. In the third and final part of the book, Dehaene describes the "Four Pillars of Learning" or the four essential components that facilitate learning to occur, namely, *attention, active engagement, error feedback,* and *consolidation*.

Part One: The "What" Question

Dehaene begins the first chapter by providing a general definition of learning, "an internal model of the external world" (p. 5), and then proceeds to build upon this definition with seven additional definitions for learning. These include adjusting the parameters of these mental models through trial and error and experience; building a hierarchical model that allows one to find regularities in the environment leading to the discovery of more complex structures; exploring possibilities using randomness, which creates new insight in order to solve problems; optimizing one's metacognition in order to progress forward and avoid failure; simplifying by making generalizations that can then be applied to new situations; and finally exploiting the innate knowledge that as a species we have internalized through evolution, a kind of Darwinian algorithm endowed in us. In these definitions, Dehaene weaves between human learning and artificial intelligence, as a way to show how "internal models emerge, in both brains and machines" (p. 3).

In Chapter 2, Dehaene argues the subtitle theme of his book that human brains still learn better than machines. He proceeds to describe various learning skills that humans have, but artificial intelligence still lacks from the learning of abstract concepts to social learning. He then focuses on two skills that humans excel at and are key to learning: our "relentless search for abstract rules" (p. 35) and how "the brain behaves like a budding scientist" (p. 43). A couple examples he provides regarding abstract rules illustrates the efficiency of young children in acquiring language. First is the crucial rule called "shared attention" whereby children can infer that the gaze of the speaker is connected to what is being said. The white sclera in the eye has been referred to as the "cooperative eye" since it enhances the detectability of the eye gaze as a source of social information and for communication (Kobayashi & Kohshima, 2001). A second rule Dehaene describes is called the "mutual exclusivity assumption." This means children learn that each thing tends to only have one name. Therefore, if a child hears a new word like "butterfly," the child knows that it does not refer to something that already has a name like a "tree" that is within the child's visual field, but rather to something else that does not yet have a name (for the child) such as the flying object with colorful wings. Having such a rule accelerates learning. The second important skill for learning is to behave like a scientist. This refers to the idea that children use the available data they have to perform statistical reasoning, which allows them to draw a conclusion based on the probability that it is correct. This predictive mind relies on both innate, a priori assumptions, which are "top-down," and motor sensory interactions with the environment, which are "bottom-up." The convergence of these two levels of insight builds the mental model of our world.

Part Two: The "How" Question

In the first part of the book, Dehaene aims to answer "what" exactly learning is by reviewing a set of definitions that set the stage and provide the reader some background on the topic. Now, in the second part, he examines the more nuanced part of learning or the "how" question, as in, how do we actually learn. To accomplish this, Dehaene first begins Part Two (Chapter 3) with a refutation of the tabula rasa proposal by empiricists like

John Locke by showing the extensive knowledge that babies have from birth. Using experimental methods that rely on the reaction of babies (e.g., gaze length and surprise), he describes research that shows babies from a very young age have knowledge of concepts and the laws of physics, an abstract sense for numbers, the ability to make probabilistic inferences and discriminate between animate and non-animate things, and a strong sensitivity to human face perception. Thus, he asserts that evolution has endowed humans with a number of innate complex and abstract abilities likely from birth. In the final section of this chapter, Dehaene describes language as an instinct, referring to Stephen Pinker's book *The Language Instinct* (1994). This line of reasoning is premised on the "poverty of the stimulus argument" or the notion that children know things about their native language that they could not have learned from their immediate linguistic environments. To which Dehaene explicitly states that he agrees with Chomsky and the generativist view that humans have a "language acquisition device" (p. 67) or some form of innate, instinctual, and biological apparatus for acquiring language. This will be further discussed and critiqued in the final section of this review.

Dehaene continues in Chapter 4 to reject the empirical claim that the baby comes into the world as a tabula rasa, but instead with well-organized cortical structures and specialized modules for language and spatial and temporal encoding. For example, research where babies listen to sentences in an MRI[2] have shown that the "language highways" (such as the arcuate fasciculus) are already formed in the baby's brain. The arcuate fasciculus is a bundle of fibers that connects the temporal sensory region (Wernicke's area) and the frontal motor region (Broca's area) and has been well established in the literature as the anatomical circuitry for language (Axer, Klinger, & Prescher, 2013; Gescwind, 1970). In addition, he discusses research with grid cells and the entorhinal cortex,[3] which provide humans along with many other species an internal compass or neuronal GPS system. The main focus of this chapter is to demonstrate that despite some degrees of variation between individuals, humans in general "share the same initial brain structures, the same core knowledge, and the same learning algorithms that allow us to acquire additional talents" (p. 80). As a consequence of these shared brain structures and core knowledge that have evolved over millennia, we have an innate ability for things such as mathematical reasoning and language acquisition.

In the first two chapters of this section, Dehaene focuses on the innate and extraordinary abilities of babies as they enter the world. Chapters 5 and 6 then shift the focus to the nurture side and the important role the environment plays on the brain's organization and development. Dehaene first outlines in detail the workings of neurons and their role in learning, succinctly stated by Donald Hebb (1904–1985) "neurons that fire together wire together" (p. 87). So, during learning, the individual is altering or strengthening synaptic connections between a set of neurons. In other words, learning changes the anatomy of the brain. Then, Dehaene provides a textbook description of the memory system and next illustrates the limits, but also the power, of brain plasticity. He finally describes different sensitive periods for brain plasticity from earlier regions like the visual cortex to regions that mature later in life like the higher-level cortical areas in the prefrontal cortex. One sensitive period that has been well studied is the acquisition of phonemes in a foreign language, and the gradual decline in one's ability with age to distinguish the sounds of another language. He clearly notes that this ability is not impossible, but the learning capacity shrinks, therefore making it a lot more difficult with age. However exceptional babies are for learning, Dehaene asserts that plasticity never fully disappears; it only diminishes, and thus the potential for learning continues throughout one's life.

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[2] An MRI is a very common and non-invasive brain imaging technique that highlights anatomical structures that are active while the individual performs an activity such as language comprehension.

[3] See for more information: https://www.nobelprize.org/prizes/medicine/2014/press-release/

In Chapter 6, Dehaene introduces to the reader a collection of his previous studies and books, particularly his hypothesis on "neuronal recycling," which suggests that "the human capacity for cultural learning relies on a process of pre-empting or recycling preexisting brain circuitry" (Dehaene, 2005 p. 134). At the heart of this idea is that our brains have anatomical constraints based on evolutionary pressures and yet also are highly malleable. To account for this malleability, new cultural knowledge must find a "neuronal niche" within the pre-existing neural architecture of the brain. This repurposing is not done randomly, but selected based on the new function as being sufficiently similar to the existing function. This neuronal recycling hypothesis explains how apt humans are at acquiring new skills and knowledge since it "occurs within an individual brain and on a much shorter time frame" (p. 123) than a genetic modification, which occurs over thousands of years. So, in short, "to educate oneself is to recycle one's existing brain circuits" (p. 122). Using his previous research with mathematics and reading (see the beginning of this review), he shows how these two learned activities restructure the brain. For example, mathematics recycles brain circuits for representing approximate numbers and quantities that humans and other primates have from birth. Therefore, learning mathematics is the extending, modifying, and building up of these preexisting neural structures. These are fixed and invariant among individuals regardless of one's sensory experiences and he proves this using his own research with blind mathematicians. In regards to reading, Dehaene describes how literacy creates a visual pathway to the language circuits in our brain. Learning to read repurposes a region of the visual cortex that he and a colleague refer to as the "visual word form area." He concludes the chapter by reaffirming his argument that both nature and nurture play important roles in learning, as the "the child's brain is both structured and plastic" (p. 140), so there are great benefits to providing learners with a rich environment–both in school and at home.

Part Three: The Pillars for Learning

In the third and final part of this book, Dehaene describes what he refers to as the four pillars of learning, which play "an essential role in the stability of our mental constructions" and "optimize our efforts" while learning (p. 145). Chapter 7 is dedicated to the first pillar, attention, or the ability to allocate cognitive resources to focus on a selected bit of incoming information. Obviously, information that is unattended or one does not pay attention to has no chance of being learned. Dehaene then describes three major attentional systems; the "when" system, which alerts and awakens the individual to attend to something; the "what" system, which orients the individual to filter out other stimuli in order to focus on a specific object of interest and amplify its resonance; and finally, the "how" system, which acts as the executive control and determines the action to take. He concludes the chapter by describing how the attentional system of children is tightly attuned to others around them, particularly adults, and we attend to what others are attending to, which makes us an optimal social learning species. The second pillar, active engagement, emphasizes the importance of engaging and exploring hypotheses. That is to say, when one is actively engaged in learning, one processes the information at a deeper level. There is little learning when one is passive. Dehaene then considers the importance of two psychological constructs, curiosity and motivation, for driving the individual to explore in order to better understand the world and consequently fill in gaps to one's mental model of it. Error feedback, the third pillar, Dehaene focuses on the significance of failure and subsequent feedback for learning to occur. When one encounters in the environment information that violates an expectation, one is surprised, causing one to seek new information in order to correct the internal model. In Chapter 10, which is about the 4th and final pillar, consolidation, Dehaene spends most of the chapter describing the benefits of sleep for consolidating what has been learned during the day.

A Critical Review of the Book

The book is written for a general audience; however, it contains a lengthy notes section with references to studies Dehaene refers to throughout the various chapters. Therefore, it is a valuable resource for those who want to examine the themes of the book in more detail. Moreover, the book is a welcome contribution to the growing field of neuroeducation. Educators from primary to tertiary institutions would likely benefit from reading this book, as a way to better understand the brain mechanisms for learning and consider practical ways to enhance and optimize learning for their students. Many of the "pillars" presented in this book such as the importance of attention, being actively engaged in the learning task, and providing immediate feedback are likely familiar and well understood by experienced teachers. However, Dehaene includes interesting anecdotes and research that shed light on how important they are for supporting the learner during the learning process.

The following are a couple of minor criticisms. First, as a proponent for emphasizing that both biologically prewired neural architecture and experiences are involved in higher order cognitive processes like learning and language, Dehaene repeatedly criticizes the tabula rasa theory throughout the book, which felt distracting and tiresome. Secondly, there seems to be a considerable amount of recycling in this book, as many of the ideas within it refer back to his previously written books on mathematics and reading. This is especially apparent in the chapter on "recycling your brain" (Chapter 6). Moreover, it is also quite surprising that Dehaene does not mention the work of Anderson (2012, 2014) in this chapter, considering the similarity, but also differences between Dehaene's "neuronal recycling" hypothesis and Anderson's "neural reuse" theory. This would be especially useful to the reader and provide a more in-depth view towards enculturation or the important roles played by the environment, the body, and the brain in learning and cognitive development (see Jones, 2020 for a review of the explanatory powers of "neuronal recycling" and "neural reuse" for numerical cognition). Thirdly, those who have a background in sociocultural theory of cognitive development (e.g., in the tradition of Vygotsky) might find this book to be steeped in the metaphor, "the mind is a computer", and thus view Dehaene as overplaying the importance of the machinery of the brain and underplaying the important role of the social in child development. Finally, below are two in-depth criticisms of this book regarding language as an instinct, which he argues for in Chapter 3, and the four pillars from a teaching perspective.

Language is an Instinct: Or Is It?

In Part Two (Chapter 3), Dehaene refers to a book by Pinker (1994) to argue that language is an instinct. Even though Dehaene's book is for a general audience, it still overlooks the tenacious debate surrounding this topic and how many linguists and cognitive scientists disagree with this "language as an instinct" assumption. If we assume that the word, instinct, refers to a conventional and invariant species-specific behavior that would appear even if the species were raised outside its natural environment (Tomasello, 1995), then a child who grows up in isolation should still develop language like a spider develops the ability to spin a web. Yet, humans raised outside their species-specific environment fail to develop language (e.g., feral children). Therefore, this suggests that language is a social construction that relies as importantly on social interaction and usage than built-in neural circuitry. Moreover, if language is an instinctual species-specific behavior, then there must be an underlying Universal Grammar (UG) (Chomsky, 1986) residing in a language module of the brain that has encoded or "hardwired" the universal principles of language structure. However, this is a highly contested assumption (see Evans & Levinson, 2009; Tomasello, 1995, 2009) and others suggest that "a biologically determined UG is not evolutionarily viable" (Christiansen & Chater, 2008, p. 489). There is no doubt that the brain has evolved to learn language, but this capability is rather fluid, and not hard-wired in the brain as some language module. As research with blind subjects has shown "the potent role of experience in determining the functional consequences of anatomical predispositions.

Experience can do more than modifying the sensory modality that drives a cortical area: it can drastically change its cognitive role" (Bedny, 2017 p. 638) and "cerebral organization of complex cognitive systems such as the language system is significantly shaped by the input available" (Röder et al., 2002, p. 930). It is hard to imagine how Dehaene argues for both nature and nurture, but then quite contradictorily states that it is an instinct? This is clearly not the case (just as the brain is not a tabula rasa) and propagating this language myth continues to obstruct important research pathways into the ontogeny of language development from a usage-based (see Bybee, 2010; Tomasello, 2003) and constructionist perspective (Goldberg, 2003).

The Four Pillars of Learning: An Educational Perspective

It would be hard for any teacher to argue against any of these four pillars; attention, active engagement, error feedback, and consolidation, as being crucial for learning to occur. Yet, from a practical perspective, what can a teacher do to develop active engagement in their students to explore and become more curious and motivated learners? This chapter would have benefited from the wealth of research done with self-determination theory (Deci & Ryan, 2000) and the important role of satisfying the learners' basic needs of autonomy, competence, relatedness, and novelty (Birdsell, 2018; Deci & Ryan, 2000; González-Cutre et al., 2016). If these needs are thwarted, it is very hard for any learner to ever become "actively engaged" and therefore certain needs have to be satisfied for this pillar to stand firm. Furthermore, the chapter on consolidation looks at in depth, the important role sleep has for consolidation. However, from a practical point of view, teachers have minimal influence on the learners' sleep schedules. On the other hand, this chapter surprisingly does not take into account a growing body of research that shows the benefits of movement and exercise for learning (Hilman, Erikson & Kramer, 2008; Madan & Singhal, 2012), especially in regards to memory consolidation. For example, gesture has been shown to facilitate vocabulary learning (Macedonia & von Kriegstein, 2012; Morett, 2014), enacting the meaning of the target language has been shown to improve memory retention (Birdsell, 2021; Lindstromberg & Boers, 2005), and finally an emerging body of research has documented the positive impact a short bout of exercise has on vocabulary encoding (Schmidt-Kassow et al. 2014).

Conclusion

In conclusion, Dehaene's *How We Learn* is an enjoyable and thought-provoking book about how humans learn to which he insists involves both nature and nurture, and few would argue against this assertion. It also provides the reader, teachers, and others interested in education insight into how to optimize learning for students. Most importantly, it provides another block in the bridge that connects the neurosciences with education and shows how crucial it is for cross fertilization between these two fields. Each of these two fields can reciprocally contribute new ideas and supporting evidence into theories of how humans learn and develop and at the same time design best approaches to facilitate learning.

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