Book Review

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Review of How We Learn. The New Science of Education, Stanislas Dehaene, Allen Lane 2020

Stanislas Dehaene is a pioneer of the multi-disciplinary study of learning. His latest book is an accessible description of the physiological and computational mechanisms that underpin learning. As such it will be invaluable for classroom teachers who seek a more nuanced view of how to design mathematical tasks and assess children's understanding than offered by mainstream knowledge transmission theories.

Dehaene and his colleagues work at the boundaries of computer science, neurobiology and cognitive psychology. Their work with functional magnetic resonance imaging (fMRI) over the last 30 years has overturned traditional theories that held that babies are born as blank vessels to be filled with knowledge and facts about the world. It contradicts influentual mathematics and computing education pedagogy, such as Sweller's cognitive load theory (CLT) - a knowledge transmission perspective on learning. CLT holds that the 'natural', minimal guidance procedures used to acquire biologically primary, generic-cognitive skills (such as speaking) are inappropriate for the acquisition of biologically secondary, domain-specific skills (such as mathematics) that tend not to be acquired easily, unconsciously or automatically. CLT emphasises explicit instruction for domain-specific skills.

In contrast Dehaene formulated the neuronal recycling hypothesis - that each new cultural object we invent, such as the alphabet or Arabic numerals, must find its 'neuronal niche' in the brain: a set of circuits whose initial function is sufficiently similar to its new cultural role, but also flexible enough to be converted to this new use. He shows how, from birth, the child's brain must already possess two key ingredients: all of the machinery that makes it possible to generate a plethora of abstract formulas (a combinatorial language of thought) and the ability to choose from these formulas wisely, according to their plausibility given the data. He shows that computational phenomena are central to learning, and that learning is more than computation.

In this theory to learn is to form an internal model of the external world. They propose an object-oriented simulation theory of learning. Each region of the brain has its own preferred dynamics to which it remains faithful. Each projects its own space of hypotheses onto the world: one tries to fit the incoming data on a straight line, another tries to display them on a (2-D) map, a third on a syntax tree. These 'hypothesis spaces' precede learning, and, in a certain way, make it possible. In this way, each brain module constrains the assumptions of the next one, by exchanging messages that convey probabilistic predictions about the outside world.

The theory proposes that these signals express the realm of hypotheses that our brain considers plausible and wishes to test. In sensory areas these top-down assumptions come into contact with 'bottom-up' messages from the outside world, for instance from the retina. The theory says that the brain should calculate an error signal: the difference between what the model has predicted and what has been observed. A Bayesian algorithm then indicates how to use this error signal to modify the intended model of the world. Relatively quickly, the algorithm converges toward a mental model that fits the outside world.

The foundations of effective learning are present at every level of processing. They are generating a prediction, detecting one's error and correcting oneself.

An emerging science of education must of course offer more than reflection on learning phenomena from multiple disciplines. The scientist seeks to isolate the essence of the phenomena that are being studied, and offers a unit for analysis and synthesis. Chemistry for example has the atom, biology the cell and computation (informatics) has the bit.

Dehaene's approach has a strong affinity with Gattegno's science of education. Gattegno proposed an 'awareness' as an appropriate unit of analysis for learning. We can use his framework to account for Dehaene's ingenious experiments with babies in which surprise is taken as an indication of computational awareness and to analyse McCandliss's adult reading experiments in which he directs attention ('forces awareness') to lexemes in an artifical ideographic language.

Dehaene and his colleagues have isolated computational structures that underpin reasoning, they have established that babies are aware of them and through fMRI they have identified a physiological manifestation of their awareness in a cascade of message-passing in the brain. The implications for mathematics education are far reaching - from progression to text book design to parental education. Much still remains to be done, both in general to abstract a science of education from these experiments, and in particular to adapt the teaching of school mathematics to take account of children's mental powers.