SPOTLIGHT 1

The biology of learning

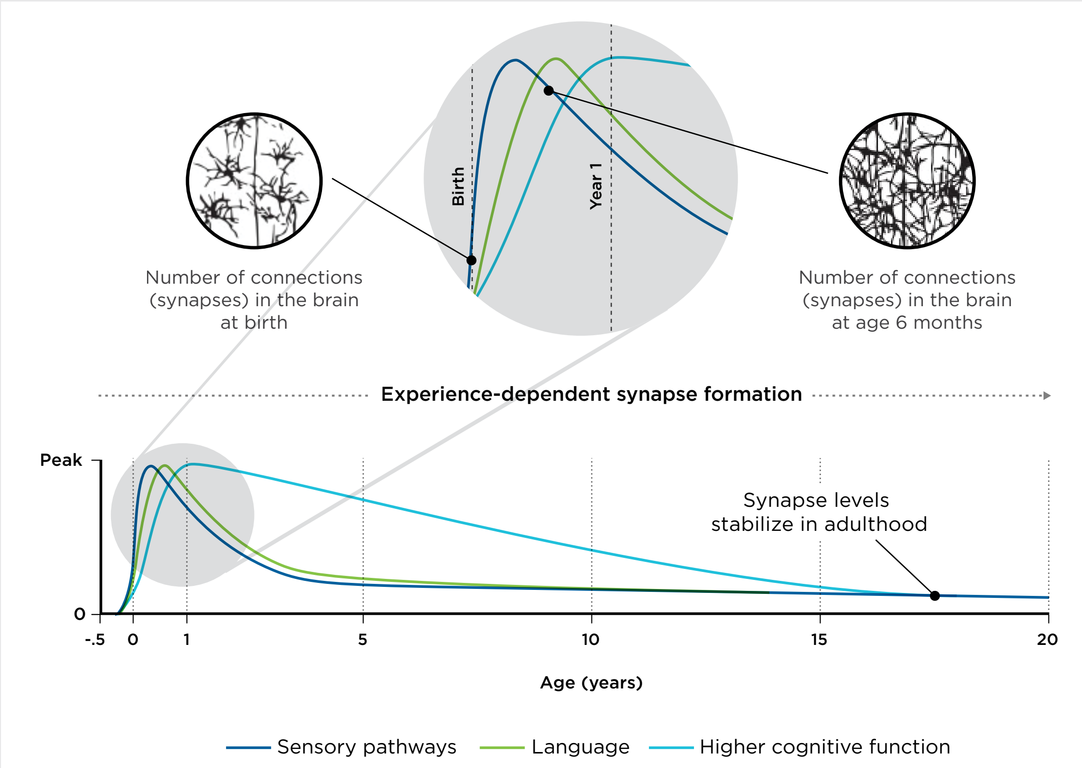
Research has dramatically expanded our understanding of how the brain works—and therefore how people learn. The brain is very malleable: it adapts to its surroundings. This phenomenon is called *neuroplasticity*, which means the ability to learn is dictated not only by genetic endowments, but also by how genes interact with experiences and environmental inputs. Genes govern when specific brain circuits are formed, but experiences can turn those genes on or off, as well as determine which neural connections—synapses—survive over the life cycle. Environmental inputs such as caregivers' or teachers' stimulation, or nutrition, or violence shape the architecture of the brain from the formative years on.[1]

The brain is malleable throughout life, even if most brain development is completed by late adolescence or early adulthood. The fastest synaptic growth (thus malleability) occurs between the prenatal period and age 3 (1 million new neural connections a second), with growth then gradually slowing.[2] Because different parts of the brain develop at different times, and because neuroplasticity is highest during developmental stages, not all areas of the brain are equally malleable at the same time (figure S1.1). The periods of greatest plasticity, or "sensitive periods," whose length varies widely by brain region, are characterized by an initial stage in which the brain develops far more synapses than it needs. That stage is followed by synaptic pruning in which, to maximize efficiency in brain functionality, the neural connections used more often grow more permanent, while those used less are discarded to reach optimal levels of synapses (that is, the adult level of synapses in figure S1.1).[3] Because most sensitive periods take place early in life, a 3-year-old has, in total, far more brain synapses (about 1 quadrillion) than an adult (100–500 trillion).

Although different parts of the brain have different sensitive periods, their development is interdependent. Neural circuits (series of synapses) form sequentially and cumulatively: simpler networks develop first, more complex ones later. Just as with the construction of a house, the robustness of progressively more complex brain structures depends on the robustness of foundational ones. For example, the development of increasingly complex skills and functions builds on circuits formed earlier: linguistic development relies on visual and auditory functions that are dependent on neural circuits lower in the hierarchy, which are most malleable earlier in life; neural circuits that support higher cognitive functions, most malleable until as late as adolescence, build on sensorial stimuli as well as linguistic development.[4] Moreover, physical, sensory-motor, cognitive, and socioemotional development are interdependent, constituting a web of dynamic links that ultimately determine a person's ability to thrive. For example, higher levels of health promote learning; emotional security fosters child exploration, which leads to learning; and higher self-regulation reduces health risks.[5]

A range of enriching experiences leads to more complex synapses, but cumulative exposure to risk factors (such as neglect or violence) either eliminates synapses associated with healthy brain development, or it consolidates those associated with unhealthy development. Experiences affect the architecture of the brain in part because of the hormonal response they trigger. Hormones such as dopamine (triggered when the brain encounters novelty) stimulate information absorption,[6] whereas hormones such as cortisol (associated with stress as well as negative emotions) can shut off learning.[7]

Figure S1.1 Synapse development over the first 20 years of life



Sources: Parker (2015); Thompson and Nelson (2001). Adapted with permission from Lawson Parker/National Geographic Creative; further permission required for reuse. Synapse drawings based on Golgi stain preparations (1939–1967) by J. L. Conel.

Note: The figure is a representation of synapse development for selected brain functions over the life course. Not drawn to scale.

The available insights on brain development have implications for investments in learning and skill formation. Because brain malleability is much greater earlier in life and brain development is sequential and cumulative, establishing sound foundations can lead to a virtuous cycle of skill acquisition. Moreover, investment in experiences and environmental inputs that foster learning at the very earliest stages increases the impact of investments at later stages: *skills beget skills*.[8] Weak foundations, by contrast, result in the accumulation of learning gaps, as well as higher risks of poor biological development that hamper skill formation—with repercussions over the life cycle (see chapter 5). Yet the optimal periods for cultivating higher-order cognitive and socioemotional skills occur throughout childhood, adolescence, and early adulthood.[9] Furthermore, the brain's ability to adapt to its environment, learn, and acquire new skills continues throughout life (that is, the experience-dependent synapse formation in figure S1.1). Thus investments in environmental inputs are needed well beyond early childhood to sustain learning along with skills development.

Interventions to improve learning and skills should place a greater emphasis on the areas of the brain that are the most malleable over the life course. Children's brains are most efficient at incorporating new information through exploration, play, and interactions with caring adults or peers. Because of this receptivity, preschool programs should concentrate on building foundational skills through developmentally appropriate program structures that emphasize play and interaction.[10] Although foundational cognitive skills become less malleable after age 10, some areas associated with socioemotional development remain highly malleable through early adulthood. Accordingly, interventions that aim to improve the school-to-work transition, as well as social inclusion for youth with weak foundational skills, may prove most effective when they emphasize socioemotional skills.[11]

Teaching strategies can deeply influence how students approach challenges in and out of school. Because the brain thrives when exposed to novelty, incorporating enriching opportunities for learning along with exploration may lead to better learning outcomes. Finally, intense stress or sustained negative emotions—such as those associated with crises or acute deprivation, where multiple stressors coexist—interfere with the brain's ability to learn, retain, and use information. Extended exposure to stressors is toxic for biological systems, particularly for developing brains, and it may impede disadvantaged children from flourishing in the classroom (see spotlight 2 on the effects of poverty). Consequently, programs that increase the availability of protective factors to shelter children from stress (such as nurturing care from at least one meaningful relationship that teaches children how to cope) can improve not only schooling, but also overall life outcomes.

Notes

1. Knudsen (2004).
2. Shonkoff and Phillips (2000).
3. Knudsen and others (2006).
4. Center on the Developing Child (2009).
5. Heckman (2007); Knudsen and others (2006).
6. Hong and Hikosaka (2011).
7. McEwen and Gianaros (2010).
8. Cunha and Heckman (2007); Cunha and others (2006).
9. Guerra, Modecki, and Cunningham (2014).
10. Whitebread and Bingham (2011).
11. Kautz and others (2014).

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