science of learning portal

The plastic brain

Scientists are discovering how our brain shapes our ability to learn, and how learning shapes our brain.

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Executive summary

Our brain is plastic—which means **the brain changes its connectivity and even its structure in response to learning**.

- Our first learning experiences are foundational for our later education, and experiences **in the early years of life can greatly impact later achievement**.
- Waves of overproduction and pruning back of brain connections occur until late adolescence, making **childhood a special time for learning**.
- **Our biology does not set a defined limit to what we can achieve.** The plasticity of a student's brain means the student and their teacher play an important role in constructing it.
- Although younger brains are more plastic, **our brains remain plastic throughout our lifetime**, supporting our lifelong learning ability.
- Understanding plasticity is important for students and teachers. **Our brain shapes our learning, but learning shapes our brain**.

What is plasticity?

Most of our entire stock of neurons (~86 billion) are created prior to our birth. After birth, huge changes in the connectivity between neurons occurs over childhood and beyond. These connectivity changes are an important example of what is referred to as the brain's plasticity—i.e., its ability to change. These changes are important from an educational point of view because, from the earliest years, there is an important two-way interaction between an individual's learning experiences and their brain's changing connectivity and structure. In other words, our brain shapes our ability to learn, and learning shapes our brain.

Two important types of plasticity have been identified[1]:

1 · Experience-expectant plasticity involves the overproduction of connections (or "synapses") between neurons in different regions of the brain around particular times during development. These connections are then organised and pruned back by expected or typical/common experiences. Both overproduction and pruning help "tune" basic functions during development, including vision, movement, language, and socio-emotional response (see Figure 1). The overproduction and pruning occur first in regions related to the most primary functions (e.g., vision and hearing). Brain regions that serve higher-order thinking processes develop more slowly, reaching their maximum number of connections at preschool, while their pruning back can continue in regions key for reasoning and learning late into the teenage years.

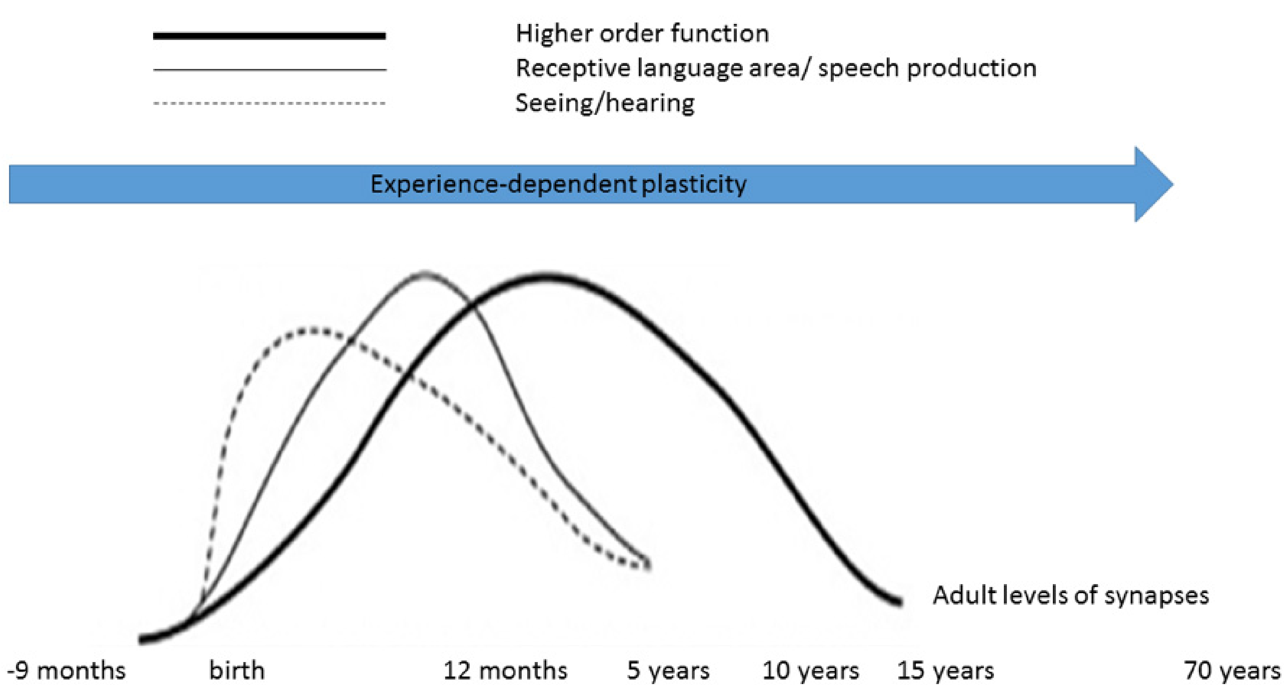

Figure 1. Synaptogenesis with age. Brain regions involved with different types of ability vary in the rate at which connections proliferate and are pruned back. Experience-dependent plasticity continues across the lifespan. (Source: Charles A. Nelson, Minnesota University[2])

So-called "sensitive periods" have been identified for some of these primary functions, including those relevant to the development of language[i]. For example, in the first year of life, infants become tuned to their native language by losing their ability to discriminate between sounds that are not represented in their social environment[3,4]. This makes later learning of that language easier but makes learning a language with different sounds more difficult. Experiencing another language in very early infancy prevents this loss[5], adding to the accumulating evidence for the mental advantages of growing up in a bilingual or multilingual environment[5,ii]. From experiments with children recognising monkey faces, a similar effect may be occurring in children's visual system, honing their brains to recognise differences in their native faces, while losing their ability to discriminate between faces of those who do not play a role in their very early social environment[6,7]. This latter effect is less well-studied but may point to the benefits of very early social interaction for gaining (or more accurately preserving) our face recognition abilities in a multi-ethnic world.

Deprived conditions in the early years can impact negatively in terms of experience-expectant plasticity. This was demonstrated by findings from the Bucharest Early Intervention Project. Here, children were randomly allocated to foster carers having suffered early institutional deprivation in Romania, which did not provide a species-typical experience in terms of sensory stimulation, touch, speech, and personal caregiving. Children formed insecure attachments, knew only a third of the number of words, and produced less brain activity than children reared in family environments[8-12]. There also appeared a time constraint, after which remediation of attachment and cognitive development by foster care was less likely (24 months)—which points to sensitive periods of development being involved.

Most of what we understand of sensitive periods relates to infancy, but given the structural changes occurring throughout childhood, later ones are likely[13,14].

2 · **Experience-dependent plasticity** involves the change or production of new connections based on experiences that would never be expected to be common to all children. These include culturally-specific skills, such as reading, writing, and mathematics. Sensitive periods are not usually associated with this type of plasticity. Plasticity has been studied in a region of the brain called the hippocampus (see Figure 2). This region should be of particular interest to educators since it has a crucial role in learning and memory. Education requires a vast amount of information to be committed to memory. This type of information first arrives at the hippocampus where it is converted into a form for storage in regions across the brain.

Figure 2. Location of the hippocampus—a critical brain structure for memory formation. This "glass brain image" shows the left hippocampus.

But this structure is not only about memory for facts and figures. For example, its size predicts the ability of children's arithmetic skills aged 8-9 years[15]. The size of the hippocampus can also be increased by a range of learning experiences[16]. Amongst adults, learning experiences that have been found to increase the size of the hippocampus include learning navigational skills[17-19]. A part of the hippocampus measured in London taxi drivers, for example, was larger than that of bus drivers, who have to navigate less. More academic examples of this type of plasticity include studying for a final medical examination[20] and intensely studying a foreign language[21]. In the example of foreign language study, measures of hippocampal growth predicted memory performance independent of time spent studying and vocabulary increase, demonstrating learning may improve one's basic ability to learn more (or "learning begets learning").

In short, scientific understanding of the role of sensitive periods is incomplete, and their role may be restricted to significant levels of disadvantage. Still, there is already a biological basis for emphasising the importance of a child's educational experience from the earliest years. This helps understand why early care, education, and experience appear so foundational to later learning and development. While academic and cognitive benefits of extra investment in the early years can sometimes fade with time, some long-term benefits can persist, such as improved rates of high school graduation and decreased teenage parenthood and criminality[22]. From the early years, the quality of the learning experience is a major factor in determining later outcomes[23,24]. Indeed, early economic models based on a "learning begets learning" principle (where learning leads to greater ability to learn) show earlier is generally better for investing in children's education[25-27]. However, one should be careful with the simple idea "learning begets learning," since it can suggest that less is returned from those who have suffered the least investment. In reality, a consistent message from the research has emphasised the particular importance of preschool and early years education for the *disadvantaged*. Maturation of abilities occurs at different times during development[14], and more sophisticated economic models have attempted to reflect this. This research shows early investment still provides the greatest economic return, but it also confirms that this would be *greatest for the least advantaged*[28]. Interestingly, the research also shows the later adolescent years may benefit more from interventions aimed at noncognitive skills[iii], which aligns with suggestions of a sensitive period during adolescence for identity formation[29].

Why does the message of plasticity matter in education?

Educational research suggests a student's theory of learning—how they think their learning comes about—can be influenced by their ideas about their brain[30]. It is important for students to understand that their brains are plastic—because their theory of learning is one determinant of their academic motivation and success[31]. In a highly-cited study, adolescents receiving a course that included concepts of brain plasticity later outperformed peers in terms of self-concept and academic attainment[32]. The plasticity of the brain means that a student, and their teacher, have an important role in constructing it. For example, teachers who believe more strongly that biology predetermines outcomes also believe they can do less for their students[33,34]. For similar reasons, it is important that teachers (and students) do not consider the brain is "fixed" at 3 years old (the enduring "Myth of 3"[14,35]) or at any other age.

Lifelong plasticity

Although the younger brain is generally more plastic, our brain remains plastic throughout our lives, and it is never too late to learn. The number of neurons in our brains is quite stable in most regions of our brain across the lifespan[36], but we also now know that as well as new connections, learning may promote the birth of new neurons. In adult humans, it has been estimated that 1,400 new neurons are added in the hippocampus region of the brain per day, with only a modest decline in this renewal during aging. The human brain's ability to produce new neurons in other important parts of the brain for learning is also now being reported[37]. A clear connection between the production of new neurons and learning has been established in animals[38], but no research of this type has yet been completed with humans. In the meantime, the positive effects of education on preserving our mental abilities in later life are clear. Education helps build up our "cognitive reserve," improving our level of cognitive functioning and protecting us from dementia[39]. Continuing to challenge the aging brain appears beneficial to maintaining its capabilities, with some "brain fitness" programmes for the elderly showing benefits that have now lasted 10 years[40].

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[i] Current knowledge of sensitive periods is mostly restricted to primary functions (sensory, motor, etc.) that develop early. There are no sensitive periods for maths, reading, etc.—these are complex abilities that draw on multiple types of basic cognitive function. Even the idea that sensitive periods are involved with age-of-acquisition effects for 2[nd] language learning is controversial. For example, this may be better considered as a reduction general plasticity of the brain and/or accumulation effects (i.e., the sooner you start the more you learn).

[ii] This process requires social interaction—it does not occur simply from, for example, having the TV or radio broadcast a foreign language.

[iii] Cognitive skills include abilities such as reasoning, memory, IQ, etc., while noncognitive skills include those more associated with traits such as self-motivation, attitude, sociability, etc.