Science of Adolescent Learning:

How Body and Brain Development Affect Student Learning

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*The **Alliance for Excellent Education** (All4Ed) is a Washington, DC–based national policy, practice, and advocacy organization dedicated to ensuring that all students, particularly those underperforming and those historically underserved, graduate from high school ready for success in college, work, and citizenship. **all4ed.org***

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Executive Summary

During adolescence, the body and brain experience a variety of biological changes that make this period of human development a time of learning opportunity and risk for students. As the human brain prepares for adulthood, its development depends strongly on the learning environment provided during adolescence. Events and activities experienced during this developmental period prepare the brain for situations and circumstances it presumes the adolescent will experience as an adult. Consequently, students in middle and high school need opportunities to develop deeper learning competencies, such as problem solving and critical thinking, and other higher-order thinking skills to support application of those skills later in life. Therefore, education leaders must ensure that learning opportunities support the development of adolescents' increasing cognitive capabilities and provide additional resources and services necessary to support learning and development of students during this period.

This report examines learning and development research that supports the Alliance for Excellent Education's (All4Ed's) Science of Adolescent Learning (SAL) Research Consensus Statements 1–5 (see page 3 for statements). The report highlights the following essential findings about adolescent learning and development:

1. While researchers once thought that early childhood was the only major period of brain plasticity, or adaptability, research now shows that adolescence is a second period of increased brain plasticity, making adolescence a critical period for students and educators.
2. The learning environment plays a significant role in brain development. As adolescents perform complex mental tasks, the neural networks that support those abilities strengthen, increasing their cognitive, emotion-regulation, and memory skills. Without opportunities to use these skills, those networks remain underdeveloped, making it challenging for individuals to engage in higher-order thinking as adults.
3. During adolescence, individuals face an increased risk for certain health issues that can affect their behavior and ability to learn.

This report also includes recommendations for how educators, policymakers, and advocates can apply adolescent learning and development research to policy and practice. By understanding the science behind student learning and development, education leaders can support adolescent learning and development throughout the entirety of the education system, closing achievement and opportunity gaps. Additionally, policymakers and educators can ensure that continuous improvement efforts at the secondary school level are comprehensive, developmentally appropriate, and support adolescents' academic, social, emotional, physical, and health needs.

About All4Ed's SAL Consensus Statement Report Series

In November 2017, All4Ed convened researchers, practitioners, and policy experts to examine advances in research and how recent findings from SAL can advance student learning and inform high school improvement strategies under the Every Student Succeeds Act (ESSA). During the event, an interdisciplinary group of researchers representing multiple scientific perspectives identified the most critical learning needs of adolescents.

After the convening, the researchers collaborated with All4Ed to develop a set of consensus statements about adolescent learning and development research, listed on pages 3–4. These statements, along with an accompanying series of reports, provide the foundation for All4Ed's SAL initiative. Each of the reports listed below translates supporting research on adolescent learning and development that informs the consensus statements, which are grouped by theme. The reports also offer key considerations for education practitioners and policymakers on how best to support adolescent learning, particularly for students from historically underserved populations:

1. *Science of Adolescent Learning: How Body and Brain Development Affect Student Learning*
2. *Science of Adolescent Learning: Risk Taking, Rewards, and Relationships*
3. *Science of Adolescent Learning: Valuing Culture, Experiences, and Environments*
4. *Science of Adolescent Learning: How Identity and Empowerment Influence Student Learning*

The following researchers, all members of All4Ed's Expert Advisory Group, endorse the consensus statements and continue to support All4Ed's SAL initiative and this report series in their respective areas of expertise:

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To learn more about All4Ed's SAL initiative, visit all4ed.org/SAL.

All4Ed's SAL Research Consensus Statements

Consensus statements featured in this report

1. In addition to body changes, the onset of puberty may trigger a second period of brain plasticity, increasing both the opportunity and vulnerability inherent in adolescence. Certain life conditions may cause the process of puberty to occur earlier or later, meaning that physical, cognitive, social-emotional, and other changes associated with puberty can begin at various ages.
2. Adolescents are in a stage of development during which the brain becomes more specialized and efficient. Learning experiences and environmental influences play key roles in this process. Learning and development are inextricably intertwined; these dual processes shape patterns of neural connections during adolescence.
3. As the brain becomes more interconnected during adolescence, young people are increasingly able to engage in adult levels of complex cognition, such as abstract reasoning, future thinking, and social cognition.
4. The ability to form memories and reflect on the accuracy of those memories continues to improve during adolescence. Adolescents become better able to assess their own learning, allowing for more time for additional information gathering and review.
5. Adolescents face an increased risk, compared to adults and younger children, for certain issues related to mental health, behavioral health, alcohol and substance use, accidents, trauma, sexual health, and nutrition due to physical, cognitive, and emotional changes they experience.

Consensus statements featured in report 2

6. During adolescence, biological and environmental changes affect motivation and mindset. Because adolescents have an increased sensitivity to social evaluation, praising their learning process and successful strategies, not effort alone, can support development of a positive mindset and motivate them to learn.
7. Adolescents are more sensitive to some types of rewards, such as social recognition, than adults and younger children. Adolescents are more likely to engage in both positive and negative forms of risk taking, especially if peers support that behavior.
8. The transition from childhood into adolescence is associated with an increased sensitivity to social evaluation, including feelings of belonging, acceptance, admiration, and respect.
9. Peer relationships strongly influence adolescents, even more so than younger children, in ways that contribute to opportunities as well as vulnerabilities.
10. Compared to younger children, adolescents are able to spend more time with peers without adult supervision. However, support, communication of consistent expectations, and monitoring of activities and emotional functioning by adults are essential as adolescents become more independent.

(continued)

Consensus statements featured in report 3

11. Culture constructs the nature of learning environments and ways adolescents experience them including their values, motivations, and beliefs related to learning.
12. Adolescents seek learning environments that are consistent with and meaningful within the social and cultural contexts of their lives.
13. Digital technologies, such as computers, the internet, social media, and smart phones, dramatically have changed the way individuals learn, play, and interact with each other. Their impacts may be greatest for adolescents who are young enough to embrace novelty and old enough to master the technologies.
14. Adolescence is marked by significant biological shifts, resulting in heightened stress-induced hormonal responses. Stress is a major modulator of human learning and memory processes. As pressures around school, work, and relationships increase, adolescents experience greater stress.
15. In addition to physical, social, and emotional impacts that economic disadvantage has on adolescents, poverty and socio-economic status are associated with a diverse set of neuroscientific structural and functional outcomes. Based on current evidence, the most sensitive systems are those related to executive functions, language, learning, and stress regulation.
16. Inequality, bias, and the persistence of structural discrimination constitute serious hazards to the positive development of all adolescents.

Consensus statements featured in report 4

17. While adolescents still are developing self-regulatory systems, under some circumstances they make more rational choices with the similar mental capacity of adults. However, the expression of self-regulatory skills depends on context and learning opportunities.
18. For adolescents, social and emotional development involves exploring meaning and finding purpose; sometimes this development is at odds with institutional structures and expectations.
19. Adolescents are developing their own adult identity, trying to understand their roles and contributions in social contexts and communities. This identity development continues into adulthood, as the individual has more diverse experiences.
20. Adolescents seek opportunities for agency where they can decide how they spend their time and influence policies and practices of institutions that shape their lives.

How the Body and Brain Affect Adolescent Learning

Several biological changes occur during adolescence, both in the body and brain, that make the adolescent years a time of great opportunity as well as one of increased vulnerability for students.[1] Furthermore, learning and development research describes how the environment plays a critical role in these biological changes, shaping even at the cellular level how students learn in ways that continue to affect their learning into adulthood.[2]

As students progress through this biological preparation for adulthood, education leaders play an essential role in ensuring that learning opportunities support the development of adolescents' increasing cognitive capabilities and providing additional resources and services necessary to support learning and development of this age group.

While adolescence often is associated with the teenage years, age is not the most accurate way of defining this important stage of development. The period of adolescence can be thought of as beginning with a biological change and ending with a social construct determined by factors like family, culture, and society.[3] This is an important distinction to make because most U.S. public schools expect students to achieve specific academic outcomes based on grade levels that, with few exceptions, largely are age based. As education leaders deepen their knowledge about how students learn and develop, they can shape the education system in ways that prepare students for postsecondary success by meeting students' specific developmental needs.

> **The period of adolescence can be thought of as beginning with a biological change and ending with a social construct determined by factors like family, culture, and society.**

The following sections examine learning and development research that supports All4Ed's SAL Research Consensus Statements 1–5 and recommend ways educators, policymakers, and advocates can apply adolescent learning and development research to policy and practice.

The Biological Beginning of Adolescence

SAL Research Consensus Statement 1: In addition to body changes, the onset of puberty may trigger a second period of brain plasticity, increasing both the opportunity and vulnerability inherent in adolescence. Certain life conditions may cause the process of puberty to occur earlier or later, meaning that physical, cognitive, social-emotional, and other changes associated with puberty can begin at various ages.

The biological change that begins the period of **adolescence** is **puberty**.[4] In addition to body changes, puberty begins a critical stage of brain development that affects adolescent learning; this is a key point for educators who work with these students to understand. The process begins when the **hypothalamus**, the part of the brain responsible for involuntary responses of the body, signals the release of **hormones**, including estrogens and testosterone.[5] While these hormones trigger biological changes in the body, studies show that some hormones associated with puberty also influence structural and functional brain development.[6] Further research still is needed, though, to investigate *how* these hormones cause these changes.

Too often, puberty is oversimplified, described as a period of quick, sporadic body changes and emotional disarray due to these "raging hormones."[7] This misinterpretation is one factor that creates a pervading view that adolescence is a time of deficit characterized by awkwardness or moodiness. But evidence for hormonally driven moodiness in adolescence is weaker than popular stereotypes suggest.[8] Some research finds little to no association of average mood or mood variability during puberty

Why the Science of Adolescent Learning Matters for Education

Adolescence is a time of transition characterized by rapid physical, neurological, cognitive, and socio-emotional development.[9] As students move toward adulthood, their bodies and minds change.[10] Those changes affect how they learn and, likewise, should influence how educators work.

A broad range of factors influence adolescent learning and development. These include *physiological* and *cognitive* factors, such as the maturation of neural pathways in the brain and the capacity to solve complex problems; *psychological* factors, such as the development of individual identity independent from parental figures; and even differing, sometimes conflicting, *cultural* and *societal* expectations.[11] Consequently, rather than being a time of deficit, adolescence is a period of immense learning and opportunity.

Research about adolescent learning and development draws from a variety of disciplines, including but not limited to neuroscience, cognitive sciences, psychology, sociology, cultural studies, and medicine. By drawing from these multiple disciplines, the science of adolescent learning (SAL) synthesizes what researchers know about adolescent learning and development and challenges traditional thinking about what it means to teach and learn during this developmental period. Furthermore, it offers a body of evidence that goes beyond simply observing students in the classroom and making assumptions about their learning and the strategies that support student needs. It provides a scientific understanding about how adolescents learn that can, and should, influence the approach to education reform.

Early childhood education benefitted dramatically from efforts to increase educator and public knowledge about the importance of the early years of life for brain development and learning.[12] Now educators, policymakers, and the public generally understand that quality education during early childhood can have lasting positive effects long into adulthood.[13] Similarly, recent evidence shows that adolescence represents a second critical window for human learning and development.[14] Consequently, education leaders have a responsibility to ensure that education systems align with research about adolescent learning and development.

among girls. Meanwhile, among boys, research finds that more advanced pubertal status is associated with positive, not negative, feelings.[15] Hormonal changes simply are one of several changing systems that emerge during puberty that may contribute to mood changes in adolescents, but research shows that hormones are not the sole causal reason for those changes.[16]

The timing and course of puberty also change based on a person's environment or experiences.[17] For example, the quality of family relationships can affect the onset and rate of puberty. Research shows that adolescents raised in homes characterized by less closeness and more conflict mature earlier and faster.[18] Meanwhile, puberty can be delayed in children who have not received proper nutrition, often due to long-term illnesses or food insecurity. Conversely, research shows that obesity can result in the earlier onset of puberty in girls, with insufficient evidence of its effect on boys.[19] Also, some young girls who undergo intense physical training for a sport, such as running or gymnastics, start puberty later than normal.[20] By contrast, such athletic activity does not appear to delay puberty in boys.[21] A delay in puberty also could occur simply because a child (male or female) matures more slowly than average, a trait that often is hereditary.[22]

Those with delayed puberty usually go through normal puberty, just at a later age. Compared to adolescents in the nineteenth century, today's adolescents, on average, start puberty at earlier ages.[23] Educators should be mindful that students develop at different rates and ages and their experiences influence how soon and how quickly their bodies and brains experience critical changes necessary for advanced learning.

The Second Critical Window of Brain Development

SAL Research Consensus Statement 2: Adolescents are in a stage of development during which the brain becomes more specialized and efficient. Learning experiences and environmental influences play key roles in this process. Learning and development are inextricably intertwined; these dual processes shape patterns of neural connections during adolescence.

Research indicates that brain changes associated with puberty trigger a second period of increased brain **plasticity**.[24] Plasticity refers to the ability of the brain to adapt and change based on experience and environment.[25] To use energy and resources efficiently, the brain prepares for an anticipated future based on an individual's current environment and needs. Experts once believed that the period of life between infancy and early childhood was the only stage of life associated with increased brain plasticity. But recent evidence shows that the brain goes through a second period of plasticity in the adolescent years, as the brain prepares for adulthood.[26] The dynamic brain development that occurs during adolescence manifests itself in several forms.

> **Experts once believed that the period of life between infancy and early childhood was the only stage of life associated with increased brain plasticity. But recent evidence shows that the brain goes through a second period of plasticity in the adolescent years, as the brain prepares for adulthood.**

In early adolescence, the human brain increases the rate at which it forms **synapses**, or connections between the brain's nerve cells. This burst of neural activity strengthens communication networks between brain regions and builds an individual's capacity to engage in complex mental tasks.[27]

Following this intense period of synaptic formation, the adolescent brain engages in high levels of **synaptic pruning**, a process that removes rarely used connections in the brain.[28] This process makes the brain more efficient by allowing it to change structurally in response to the demands, activity, and stimulation from an individual's environment, resulting in increased specialization of brain regions.[29]

Myelination, the process of wrapping neurons and their connections with fatty cells, also enhances the brain's functioning and makes it more efficient.[30] The additional fat facilitates faster electrical signals and communication between neurons, expediting completion of mental tasks. While synaptic pruning and myelination occur throughout different periods of life, during adolescence these processes occur in brain regions, such as the **prefrontal cortex**, that are involved in higher cognitive functions, such as controlling impulses and emotion regulation.[31]

Each of these processes is affected directly by an adolescent's individual needs and inputs from the environment he or she experiences. Evidence suggests that during puberty, the human brain is more sensitive to influences from an individual's environment and life experiences, making adolescence a time when quality learning opportunities and positive relationships with others can affect a student's developmental and academic trajectory significantly.[32]

Essentially, events and activities experienced during adolescence prepare the brain for environments it presumes the adolescent will experience as an adult. Consequently, when adolescents have opportunities to develop deeper learning competencies, such as problem solving and critical thinking, and other higher-order thinking skills, the neural pathways associated with those capacities are more likely to develop and mature.[33] Without these opportunities, adolescents could have more difficulty engaging in these types of higher-order thinking skills as adults, just as an athlete would need to exert more effort to win a game without prior practice.

Increased Capacity for Advanced Cognition

SAL Research Consensus Statement 3: As the brain becomes more interconnected during adolescence, young people are increasingly able to engage in adult levels of complex cognition, such as abstract reasoning, future thinking, and social cognition.

During adolescence, key brain regions involved in advanced **cognition** develop. As these regions, such as the prefrontal cortices, mature, adolescents become more capable of performing complex cognitive tasks, such as **executive functions**.[34] Executive functions are cognitive processes involving abstract thought, planning, decisionmaking, **perspective taking** (looking at a situation from a viewpoint that is different from one's usual viewpoint), and **future thinking** (visualizing, predicting, and planning for the future), among other higher-order processes. Development of these higher-order cognitive processes appears to be driven by changes in brain structure,

increased autonomy from parents, and importantly, societal contexts and expectations such as those in school settings.[35]

During adolescence, young people also further develop abilities to perceive, think about, interpret, categorize, and judge their own social behaviors and those of others—mental tasks collectively known as **social cognition**.[36] At the same time, adolescents face greater demands to regulate their emotions as they experience increased independence, hormonal changes, and a changing social environment. Evidence suggests that brain maturation and structural changes in the frontal and prefrontal cortices are linked to **emotion regulation** and plasticity of the adolescent period offers opportunities to help young people improve their abilities to process emotions. [37]

> **When adolescents have opportunities to develop deeper learning competencies, such as problem solving and critical thinking, and other higher-order thinking skills, the neural pathways associated with those capacities are more likely to develop and mature.**

Emotion regulation improves from childhood to adolescence and into adulthood, particularly an individual's ability to change the trajectory of an emotional response by reinterpreting the meaning of the emotional stimulus. This strategy is called **cognitive reappraisal** and it involves two parts: (1) recognizing a negative response and (2) reinterpreting the situation to either reduce the severity of the negative response or exchange the negative attitude for a more positive attitude.[38] For example, a student fails a series of tests and thinks negatively about his or her performance upon first receiving the results. But when the student later revisits his or her emotional response to the situation, he or she views the test results as a challenge to improve his or her performance. In research studies on cognitive reappraisal, younger adolescents show higher instances of negative **affect** (any experience of feeling, emotion, or mood) than older adolescents, suggesting that the ability to use this strategy of re-evaluating emotional responses develops during adolescence.[39]

Improved Ability for Complex Memory Tasks

SAL Research Consensus Statement 4: The ability to form memories and reflect on the accuracy of those memories continues to improve during adolescence. Adolescents become better able to assess their own learning, allowing for more time for additional information gathering and review.

Memory performance improves during adolescence in a variety of ways.[40] This improvement results largely from the increase of **white matter** in the brain, caused by myelination, and the reduction of **gray matter**, so named because this brain tissue contains only the cell bodies of neurons that are not wrapped in fatty cells giving the tissue a gray color.[41]

Studies suggest the increase in white matter within the frontal and parietal regions of the brain (as well as the networks that connect these regions) and the decrease in gray matter are associated with improvements in **working memory** performance during adolescence.[42] Working memory refers to the ability to remember accurately and manipulate information necessary for performing complex cognitive tasks, such as learning, reasoning, and comprehension, during a short period of time. For example, when students solve a problem, they must remember the original context of the problem as well as how the problem changed in response to the solutions they test mentally.

Research also suggests that as individuals transition into adolescence, they develop **episodic memory**, or the ability to remember personally experienced events associated with a particular time and place.[43] Similarly, **autobiographical memories** become more extensive in adolescence. Autobiographical memories have significant value to an individual, are the smallest unit of the life story, and are used to maintain a sense of continuity of self and identity over time. Additionally, memories (both episodic and autobiographical) created during adolescence are easier to recall later in life compared to memories created during other developmental stages.[44]

As individuals progress through adolescence, they experience improvements in the ability to reflect on the accuracy of their memories (known as **metamemory**) and the ability to remember to perform a planned action or recall a planned intention at

some future point in time (known as **prospective memory**).[45] Metamemory connects intimately with learning because it limits memory errors and promotes additional information gathering or review. Meanwhile, prospective memory tasks occur in daily life and range from the relatively simple, like remembering to turn in a homework assignment, to extreme life-or-death situations, such as remembering to take prescription medication. Prospective memory is critical for solving complex problems and planning to complete tasks necessary for academic success, such as making time to study or finish assignments.

While a few studies show a lack of improvement in prospective memory in children between ten and fourteen years of age, it is possible that the lack of improvement was related to the children's pubertal status.[46] Future studies are needed to ascertain the relationship between puberty and prospective memory performance to clarify at what stage in adolescence the ability for prospective memory develops.

A Time of Risk for Certain Health Issues

SAL Research Consensus Statement 5: Adolescents face an increased risk, compared to adults and younger children, for certain issues related to mental health, behavioral health, alcohol and substance use, accidents, trauma, sexual health, and nutrition due to physical, cognitive, and emotional changes they experience.

While the adolescent stage of development offers multiple opportunities to enhance student learning, the rapid brain and body changes that occur during this period also increase mental and physical health risks.[47] Moreover, research shows a relationship between various health concerns and poor academic performance.[48]

Several types of psychiatric disorders, including anxiety and mood disorders, psychosis, eating disorders, personality disorders, and substance abuse, first appear during this developmental stage.[49] Researchers still are studying reasons why this is the case. But an emerging consensus indicates that as the body and brain undergo multiple rapid changes, certain breakdowns or irregularities in development may cause the onset of these disorders.[50]

Furthermore, cultural beliefs about sexuality, gender roles, and attractiveness, combined with puberty, also increase the potential for certain health risks or disorders.[51] Recent research shows that during puberty, both girls and boys experience a peak in **sensation seeking**, or behaviors involving searching out and engaging in thrilling activities as a method of increasing stimulation and arousal. Boys and girls with more advanced pubertal development have higher rates of sensation seeking and greater drug use.[52] Young women entering puberty also may encounter a societal overemphasis on beauty concepts such as thinness, although such expectations can vary by demographic group.[53] This may lead to higher instances of anxiety, depression, or eating disorders among specific populations.[54]

In addition, adolescents' sleeping patterns affect their health and learning. Adolescents produce the hormone **melatonin**, which helps regulate the biological clock, about three hours later in the sleep cycle than do children or adults.[55] Consequently, adolescents find it harder to fall asleep at early hours, making it more difficult for them to get the recommended amount of sleep before having to wake for school or other responsibilities the next day. This lack of adequate sleep can increase potential health and developmental risks, such as obesity and substance use, for adolescents.[56] Additionally, poor sleep is among the most definitive health-related causes of poor academic performance.[57] By the end of puberty, the timing of melatonin production within the sleep cycle shifts back to what it used to be prior to adolescence.

Implications and Opportunities for Education Practice and Policy

Adolescence is a time when students experience multiple biological changes that create the cognitive and physiological framework necessary for advanced learning. More importantly, research shows that the environment surrounding an individual strongly influences how these biological processes take place and consequently, shape a person's learning and development. By understanding the science behind student learning and development, education leaders can support adolescent learning and development throughout the entirety of the education system, closing achievement and opportunity gaps.

Photo by Allison Shelley/The Verbatim Agency for **American Education: Images of Teachers and Students in Action**

What do these findings mean for educators?

- District and school leaders, educators, and counselors should design instructional programs and resources that increase and elevate opportunities for students to apply advanced cognitive strategies, such as metacognition and future thinking, to develop students' abilities to regulate and reflect upon their own thinking, increase their confidence, develop deeper learning skills, and improve their educational outcomes. These opportunities can occur through academic instruction as well as other school experiences. For example, educators and counselors can support students in developing future-thinking skills through college and career planning and disciplinary practices. District and school leaders should ensure equitable opportunities for all adolescents to access rigorous extended extracurricular learning opportunities that develop higher-order thinking skills, such as debate or robotics clubs.
- Educators should capitalize on adolescents' increased ability to remember personally relevant information by connecting academic learning to students' personal interests, prior knowledge, and current events. Teachers can develop students' working memory skills by designing assignments and assessments that require students to solve complex problems and connect information to their own experiences, rather than simply regurgitate memorized information.
- District and school leaders should provide teachers and counselors with support and professional learning necessary to provide students with guided opportunities to develop social and emotional skills and emotion-regulation strategies, such as cognitive reappraisal, as they navigate increasingly complex social environments. This might mean designating time during the school day, such as an advisory period, for adults in the school to discuss timely social issues with students.
- Health and physical education classes can improve students' knowledge about the body changes they experience during adolescence and how to care for themselves during this time of rapid development and as adults. In addition to offering formal opportunities for this type of learning, schools and districts should develop informal learning structures to engage parents, students, and communities to empower students to make healthy choices for themselves. These could include offering workshops or providing video clips on the importance of sleep and preparing healthy meals during parent-teacher-student association meetings or partnering with community public health organizations to provide resources and access to community clinics and other resources.

What do these findings mean for policymakers and advocates?

- Adolescence matters, yet evidence suggests that Title I funding, the federal government's primary source of financial support for underserved students, is allocated disproportionately to elementary schools.[58] School districts should use new flexibility provided under ESSA to target Title I funds toward high-poverty high schools.
- New research on brain science suggests that adolescents need opportunities to develop critical-thinking skills, otherwise the neural networks responsible for complex reasoning will remain underdeveloped, making it more challenging for individuals to engage in higher-order thinking as adults. Because assessments affect instruction significantly, states should encourage students to develop critical-thinking skills by using new flexibility provided under ESSA to embed complex performance tasks into statewide assessments.[59] (For more information about the opportunities ESSA offers states and districts to connect policy and practice to adolescent learning and development research, see All4Ed's report *Synapses, Students, and Synergies: Applying the Science of Adolescent Learning to Policy and Practice*.)
- The recent reauthorization of the Carl D. Perkins Career and Technical Education Act (Perkins) presents an important moment to support the science of adolescent learning.

States should use new opportunities in the law to develop partnerships among school districts, institutions of higher education, and employers to provide historically underserved students with opportunities to participate in college and career pathways that include work-based learning to develop students' higher-order thinking skills while preparing them for postsecondary education.

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Conclusion

Contrary to previous belief, early childhood is not the only period of significant brain development. Recent evidence shows that adolescence is a second period of brain plasticity and cognitive development, making those years a critical time for students and educators.

Education leaders should understand that adolescence presents a significant period for both learning opportunity and risk for students. As the brain prepares for adulthood, its development depends strongly on the learning environment and experiences provided during adolescence. Consequently, during middle and high school students must practice the types of complex cognitive and interpersonal skills necessary for postsecondary success.

> **[N]eurological and cognitive gains made through quality early childhood and elementary education may diminish if efforts to align policy and practice with learning and development research are not sustained in secondary school.**

If students do not have these opportunities, essential neural networks will remain underdeveloped, unnecessarily increasing the challenge of engaging in higher-order thinking as adults. In fact, neurological and cognitive gains made through quality early childhood and elementary education may diminish if efforts to align policy and practice with learning and development research are not sustained in secondary school.

Policymakers and educators should ensure that continuous improvement efforts at the secondary school level are comprehensive and developmentally appropriate. District and school leaders should design organizational structures, including academic support systems, school improvement efforts, structures that foster positive relationships, and wraparound services that respond to the learning and developmental needs of adolescent learners, supporting their academic, social, emotional, physical, and health needs.

Endnotes

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Glossary

abstract thinking. Thinking characterized by the use of general ideas or concepts. Compare to *concrete thinking*.

adolescence. The period of human development that starts with biological changes associated with puberty and ends once specific social expectations—determined by factors like family, culture, and society—are met.

affect. Any experience of feeling or emotion, ranging from suffering to elation, from the simplest to the most complex sensations of feeling, and from the most normal to the most pathological emotional reactions. Often described in terms of positive affect or negative affect, both mood and emotion are considered affective states.

autobiographical memory. A person's memory for episodes or experiences that occurred in his or her own life. Often the terms "autobiographical memory" and "episodic memory" are used interchangeably. However, autobiographical memory can consist of information stored in episodic memory (i.e., events experienced at a particular time and place), semantic memory (i.e., knowledge of general facts and concepts that give meaning to information), or a mix of the two. For example, the autobiographical memory of one's first day at school might contain episodic information, such as meeting the teacher, but it might also contain semantic information, such as knowledge that the teacher's name was Susan. Compare to *episodic memory*.

cognition. All forms of knowing and awareness, such as perceiving, conceiving, remembering, reasoning, judging, imagining, and problem solving.

cognitive reappraisal. The ability to change the trajectory of an emotional response by reinterpreting the meaning of the emotional stimulus. Cognitive reappraisal involves two parts: (1) recognizing a negative response and (2) reinterpreting the situation to either reduce the severity of the negative response or exchange the negative attitude for a more positive attitude.

concrete thinking. Thinking focused on immediate experiences and specific objects or events. Compare to *abstract thinking*.

dendrite. A branching, threadlike extension of the cell body that increases the receptive surface of a neuron.

emotion regulation. The ability of an individual to alter or adjust an emotion or set of emotions. *Explicit emotion regulation* requires conscious monitoring, using techniques such as learning to construe situations differently to manage them better, changing the target of an emotion in a way likely to produce a more positive outcome, and recognizing how different behaviors can be used in the service of a given emotional state. *Implicit emotion regulation* operates without deliberate monitoring; it modulates the intensity or duration of an emotional response without the need for awareness. Emotion regulation typically increases across the lifespan. Also called *emotional regulation*.

episodic memory. The ability to remember personally experienced events associated with a specific time and place. In addition to recalling facts of a past event, an individual must engage in "mental time travel" and remember that he or she was the one who lived the event. Compare to *autobiographical memory*.

executive functions. Basic cognitive processes, such as attentional control, cognitive inhibition, inhibitory control, working memory, and cognitive flexibility. Higher-order executive functions require simultaneous use of multiple basic executive functions and include planning, reasoning, and problem solving. These functions frequently are associated with neural networks that include the frontal lobe (see Glossary for definition), particularly the prefrontal cortex (see Glossary for definition).

fixed mindset. The belief that attributes and abilities inherently are established and unchanging. Compare to *growth mindset*.

frontal lobe. One of four main lobes of each cerebral hemisphere of the brain. It is concerned with motor and higher-order executive functions. Compare to *parietal lobe*.

future thinking. Thinking focused on visualizing, predicting, and planning for the future.

gray matter. Any area of neural tissue that is dominated by cell bodies and devoid of myelin (fatty cells), such as the cerebral cortex and the H-shaped periaqueductal gray of the spinal cord. Compare to *white matter*.

growth mindset. The belief that abilities and intelligence can be developed. Compare to *fixed mindset*.

hippocampus. A seahorse-shaped part of the forebrain—located in the region of the temporal lobe—that is important for declarative memory and learning.

hormone. A substance secreted into the bloodstream by an endocrine gland or other tissue or organ to regulate processes in target organs and tissues.

hypothalamus. Part of the brain with primary control of the autonomic (involuntary) functions of the body. It also integrates autonomic activity into appropriate responses to internal and external stimuli. Additionally, it is involved in appetite, thirst, sleep, and sexuality.

melatonin. A hormone that helps regulate seasonal changes in physiology and may influence puberty. It is implicated in the initiation of sleep and in the regulation of the sleep-wake cycle.

metacognition. Awareness of one's own cognitive processes, often involving a conscious attempt to control them.

metamemory. Awareness of one's own memory processes, often involving a conscious attempt to direct or control them. It is an aspect of metacognition.

myelin. The substance that forms the insulating sheath around the axons of many neurons. It consists mainly of fatty cells, with additional myelin proteins, and accounts for the whitish color of white matter.

myelination. The process of wrapping neurons and their connections with fatty cells.

neuron. The basic cellular unit of the nervous system. Each neuron consists of a cell body; fine, branching extensions (dendrites) that receive incoming nerve signals; and a single, long extension (axon) that conducts nerve impulses to its branching terminal. The axon terminal transmits impulses to other neurons or to effector organs (e.g., muscles and glands) via junctions called *synapses* or neuromuscular junctions. Axons of neurons are often surrounded by a myelin sheath (fatty cells). In contrast to other cell types, neurons possess the capacity to modify their structure and function based on receipt of information and stimuli from their immediate environment. Also called *nerve cell*.

parietal lobe. One of four main lobes of each cerebral hemisphere of the brain. It occupies the upper central area of each hemisphere, behind the frontal lobe, ahead of the occipital lobe, and above the temporal lobe. Parts of the parietal lobe participate in somatosensory activities, such as discrimination of size, shape, and texture of objects; visual activities, such as visually guided actions; auditory activities, such as speech perception; and episodic and working memory. Compare to *frontal lobe*.

perspective taking. Looking at a situation from a viewpoint that is different from one's usual viewpoint. This may involve adopting the perspective of another person or that associated with a particular social role.

plasticity. Flexibility and adaptability. Plasticity of the nervous or hormonal systems makes it possible to learn and register new experiences.

prefrontal cortex. The most anterior (forward) part of the cerebral cortex of each frontal lobe in the brain. The prefrontal cortex functions involve attention, planning, working memory, and the expression of emotions and appropriate social behaviors.

prospective memory. Remembering to do something in the future. Prospective memory contrasts with retrospective memory (remembering past events).

puberty. The stage of development when the genital organs reach maturity and secondary sex characteristics begin to appear, signaling the start of adolescence.

sensation seeking. The tendency to search out and engage in thrilling activities as a method of increasing stimulation and arousal. It typically takes the form of engaging in highly stimulating activities that have an element of danger, such as skydiving or race-car driving.

social cognition. Cognition in which people perceive, think about, interpret, categorize, and judge their own social behaviors and those of others.

synapse. The specialized junction through which neurons transmit signals from one to another.

synaptic pruning. A neurodevelopmental process, occurring both before birth and up to the second decade of life, during which the weakest synapses between neurons are eliminated.

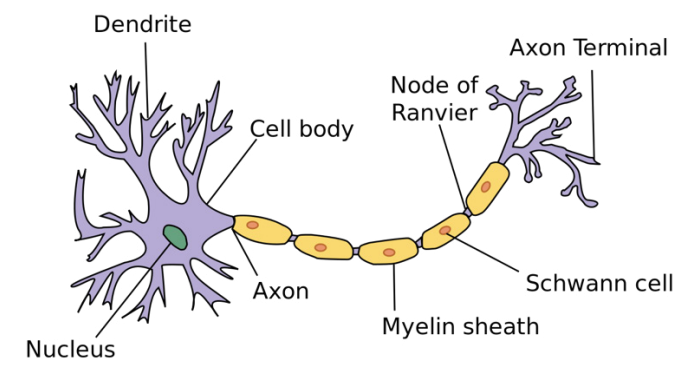
white matter. Parts of the nervous system composed of nerve fibers enclosed in a myelin sheath (fatty cells), which gives a white coloration to otherwise grayish neural structures. Compare to *gray matter*.

working memory. The short-term maintenance and manipulation of information necessary for performing complex cognitive tasks, such as learning, reasoning, and comprehension.

Sources: G. R. VandenBos, ed., *APA Dictionary of Psychology* (Washington, DC: American Psychological Association, 2007); S. Blakemore, *Inventing Ourselves: The Secret Life of the Teenage Brain* (New York: NY: PublicAffairs, Hachette Book Group, 2018); C. S. Dweck, *Mindset: The New Psychology of Success* (New York: NY: Random House, 2006); G. Oettingen, A. T. Sevincer, and P. M. Gollwitzer, *The Psychology of Thinking about the Future* (New York: NY: The Guilford Press, 2018).

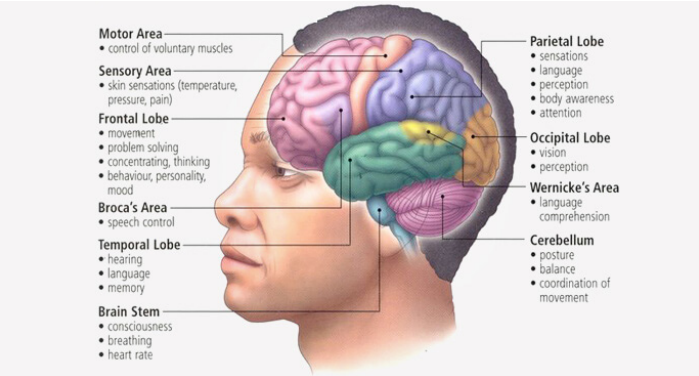
Appendix

FIGURE A1: Parts of a Neuron



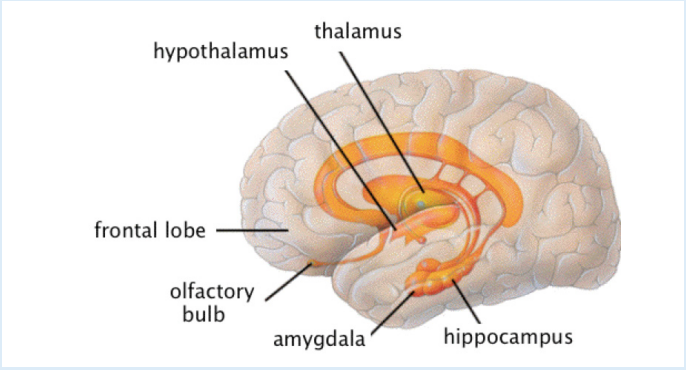
Source: U.S. National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program, "Anatomy and Physiology," https://commons.wikimedia.org/wiki/File:Neuron.svg (accessed June 1, 2018).

FIGURE A2: Areas of the Brain



Source: Human Brain Facts, "Human Brain Structure and Their Functions in Human Body," http://www.humanbrainfacts.org/basic-structure-and-function-of-human-brain.php (accessed June 1, 2018).

FIGURE A3: Limbic System



Source: C. G. Boeree, "General Psychology: The Emotional Nervous System," https://webspace.ship.edu/cgboer/limbicsystem.html (accessed June 1, 2018).

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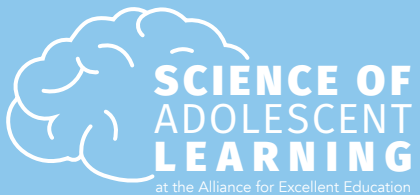

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