(Continued from page 8)

MIDDLE-LATER ADULTHOOD: Though the brain is considered to have reached maturity by middle adulthood, the adult brain undergoes age-related changes that reflect environmental, social, and educational factors.[2,108] New neurons continue to form in the brain during adulthood in response to new experiences,[109-111] but this growth can be inhibited by stress,[112,113] chronic sleep disruption,[114,115] or dietary deficiencies.[116,117] Physical and mental activity, as well as social relationships, support adults' brain functioning and help buffer against potential age-related cognitive declines.[118,119] Consistent with the biological evidence that relationships impact brain development and learning, increasing evidence points to the importance of teachers' mental health and social-emotional skills for students' success.[120,121]

Productive educational opportunities for adults build on what we know about adult learning: they connect to learners' goals and provide them with new experiences that encompass problem-solving in real-life contexts. Adults typically move through four stages in the experiential learning cycle: engaging in concrete experience; observing and reflecting, often in discussion with peers; forming insights and generalizations; and testing implications of new concepts in new situations.[122] In line with these insights, effective professional development for teachers—that is, learning that changes teaching practices and student learning—engages teachers in active learning related to the content and students they teach; supports collaboration with colleagues, typically in job-embedded contexts; uses models and modeling of effective practice; provides coaching and expert support; and offers opportunities for feedback and reflection.[123]

Evidence also shows that teachers' own social-emotional skills and wellness can be enhanced by training in mindfulness—which develops a calm attentiveness and awareness of experiences, often through regulation of breathing and physical stance, as well as through visualization. Studies find that such training reduces teachers' stress and emotional distress, helps them regulate emotions, and develops greater social-emotional competence, self-efficacy and well-being, so that they can provide more effective emotional support for students.[124-127]

The major networks of the brain provide a view into the essential dimensions of cognitive, emotional, and social processing and their developmental interdependence.

Though work on the brain from two to three decades ago sought to identify specific brain regions' unique contributions to mental processing, many scientists have shifted to a focus on the networks of connectivity between regions that facilitate different activity modes important for thinking and learning.[128,129] The basic organization of these networks appears to be present at birth and to develop across the first decades of life,[106,130-134] but it is the way the brain is used, including how a person thinks, feels, and relates to others, that strengthens and tunes these dynamic networks over time.[135] The growth and balance of these networks depends in part upon a person's environment, opportunities, and relationships, which together influence the "cross talk" of neurons within the same network and the delicate balance of activity among the networks.[136-138]

There are three major brain networks that together support a broad range of mental capacities. Through their co-regulation

and coordination, each of these networks contributes to social, emotional, and cognitive functioning, allowing a person to operate well in the world and to take advantage of learning opportunities. Extensive research in adults connects the functioning of these networks to intelligence, memory, mental flexibility and creativity, mental health, capacities for emotion regulation and attention, and other essential abilities.[139–142] In children, adolescents, and across adulthood, the functioning of these networks correlates with the quality of one's environment, resources, and relationships[2,3,143] and improves with targeted intervention.[23,34,144–146] To varying degrees, these networks appear to be malleable across the lifespan.[108]

THE EXECUTIVE CONTROL NETWORK: The Executive Control Network facilitates attention, allowing people to hold information in mind, shift strategies or approaches as necessary, and focus on the completion of goal-directed tasks.[142,147,148] The Executive Control Network is important for ignoring extraneous information and distractions, as well as for regulating emotions, maintaining goals and focus, and controlling impulses.

THE DEFAULT MODE NETWORK: The Default Mode Network is heavily recruited during all sorts of tasks that involve internally directed, interpretive, and reflective thought, for example when remembering past experiences, imagining hypothetical or future scenarios, or deliberating on inferred, abstract, or morally relevant information,[149–153] or daydreaming.[154] The Default Mode Network is important for conceptual understanding, reading comprehension, creativity, nonlinear and "out-of-the-box" thinking,[151,155,156] feelings of inspiration, social emotions like admiration and compassion,[157] identity development,[158,159] and for "looking in," or thinking about things that aren't in the physical "here and now."[151,160]

THE SALIENCE NETWORK: The Salience Network weighs emotional relevance and perceived importance and urgency of information to facilitate switching between mindsets supported by the inwardly focused, meaning-oriented Default Mode Network and those supported by the outwardly focused, task-oriented Executive Control Network.[141,148,161–163] This switching of mental modes reflects subjective, affective evaluation by the Salience Network of external signals from the environment and internal bodily signals, such as from hunger and anxiety.

Educational Implications

Optimal learning environments attend in age-appropriate ways to developing each of the broad capacities supported by the brain's major networks: this includes sustained, flexible attention and productivity on tasks (roughly speaking, the domain of the Executive Control Network); reflection, memory, and meaning-making (roughly speaking, the domain of the Default Mode Network); and emotional relevance (roughly speaking, the domain of the Salience Network).

Optimal educational activities foster engagement and learning by leveraging opportunities to strengthen, balance, and mutually reinforce these capacities in culturally relevant, meaningful, and productive tasks.[128] Productive tasks foster motivation and accomplishment by coupling interest and relevance with accessibility—representing the right level of difficulty, in the "zone of proximal

(Continued on page 14)

(Continued from page 11)

development,"[217] just beyond a learner's current competence—and supports to enable progress. To be willing and able to tackle challenging tasks, students must also learn to perceive themselves as capable of succeeding, which illustrates the connection between cognitive and emotional capacities.[89] Learning environments that are structured to be consistent with how the brain develops generally include these features:

They place the learner's emotional and social experience at the forefront. Productive learning environments attend to learners' subjective perceptions and help students build scholarly and social identities that incorporate their new skills and knowledge. They help people to feel safe and purposeful, and to believe that their work is important, relevant, and valuable.

Creating an emotionally safe environment requires schools and classrooms where strong, affirming relationships are built among adults and children. Teachers create classroom communities grounded in respect, in which all students are affirmed for their value, with shared norms and responsibilities for all members.[218] School structures support personalization, often with teaching teams that share students, advisory systems in which a small group of students are supported by a single advisor over multiple years, and looping, in which students stay with the same teacher for more than one year. Teachers actively help students develop positive academic identities by communicating their interest and belief in the competence of students who may otherwise be threatened by stereotyping and stigma, and by supporting their learning with appropriate scaffolding. Students engage in tasks as scientists, mathematicians, writers, social scientists, and artists, taking on these scholarly roles and identities while learning disciplinary concepts, skills, and modes of inquiry.[89]

They support age-appropriate exploration and discovery. Productive learning environments support age-appropriate exploration and discovery, followed by reflection and discussion for deeper understanding. They support learners in monitoring their own learning, so they can flexibly move between these modes of engagement—knowing when and how to dig in, stop and think, gather more information, or seek help—as they pursue meaningful learning goals.

To support exploration and discovery that adds up to learning important concepts and skills, teachers construct small and large tasks in which students are asked, often in small groups, to explore essential questions using scholarly tools and processes—to figure out how something works, why a phenomenon is as it appears, how to find a solution to a problem, or what will happen if something is done in a particular way—and are provided with access to materials, equipment, and manipulatives to pursue the answers.

Teachers skillfully integrate this inquiry with direct instruction and with opportunities for students to share their thinking and problem-solving strategies, so that students can put general principles and conceptual maps of the domain together with experiential information and specific disciplinary skills. Students have opportunities to teach each other, and through learning how to reflect on, evaluate, and revise their work, they increasingly take control of their own learning process.[89,219]

They support flexible and efficient thinking. Productive learning environments attend to the trade-off between plasticity and efficiency in brain development,[220,221] strategically offering activities that encourage flexible thinking along with those that encourage mastery of necessary building-block skills and knowledge.

Productive learning environments attend to the trade-off between plasticity and efficiency in brain development, offering activities that encourage both flexible thinking and mastery of necessary building-block skills and knowledge.

In the United States there has been a tug-of-war between teaching students to pursue conceptual understanding so that they comprehend ideas deeply, and ensuring that they memorize math facts, phonetic sounds, historical facts, or other pieces of information so that they can efficiently retrieve them. Often these debates are grounded in the common misconception that "basic" skills have to precede complex thinking and reasoning, which is not consistent with current models of brain network development.

True, it is important to enable students to learn symbol systems that help organize the brain for academic skills. For example, the basic academic skills of phonological decoding and mathematical calculating specialize specific brain circuits through practice over time.[222,223] However, it is also true that the very processes of reasoning, conversing, exploring, and conjecturing strengthen the coherence and balance of brain networks, fostering greater intelligence to apply to all kinds of learning tasks. Making sense of reading, for example, requires sense-making abilities and wide-ranging knowledge of the world that supports understanding of the text, as well as decoding skills and attention.[224] The most effective educational strategies typically allow students to develop conceptual understanding of domains as they engage in hands-on learning and higher-order thinking to build a foundation for situating the more specific, basic skills they will eventually make automatic—moving flexibly between exploration, reflection, and practice.[89]

In addition to basic skills and complex mental processes, various specific features of environments can enhance cognitive processing and flexibility, and beneficial character traits such as open-mindedness. For example, multilingual environments can offer cognitive, social, and emotional benefits,[225,226] as can playing a musical instrument, engaging in the visual and performing arts, and being physically active in ways that require coordination, social communication, and strategy.[227,228] These activities can enhance the development of the brain, perceptions of patterns, and reasoning ability in mathematics, visual/spatial fields, and verbal expression.[229–231]

They help students acquire habits of mind and character. Productive learning environments help students acquire habits of mind that facilitate acquisition of age-appropriate knowledge and skills, reasoning, and ethical reflectiveness.[232,233] These habits of mind become tools for navigating the world as a

learner, bringing curiosity, interest, persistence, and a deep thirst for understanding.[234]

To develop habits of mind such as curiosity, awareness of one's own understanding, and persistence—as well as empathy and ethical reasoning—teachers engage students in extended tasks that incorporate students' interests and choices, and require planning and follow through. These tasks also provide students with opportunities to exhibit and explain their thinking, gain feedback from one another, and revise their work.[235] These processes contribute to deeper learning and help students develop perseverance, resilience, and a growth mindset.[236]

Stronger achievement occurs when these tasks are undertaken in a cooperative classroom with a mastery focus where students are recognized for accomplishing their individual and collective learning goals, rather than in a competitive setting that focuses on where students rank or on what grades they have achieved.[237] An emphasis on cooperation can support more ethical and empathetic behavior, as does an emphasis on pursuing work connected to pertinent issues and problems in the world beyond their classroom.[238,239]

Conclusion

The science on how the brain develops helps explain why young people's social, emotional, and academic development are intertwined.[240,241] In addition to basic physiological needs like nutrition and sleep, brain development requires social relationships, emotional experiences, and cognitive resources, which ready the brain to take advantage of learning opportunities. To provide purposeful learning opportunities for young people—and strategic opportunities for brain development—requires educators to attend to the development of the whole child in context,[242] and to the need for aligned partnerships throughout the community that can support children's and their families' health and well-being.[215] Educating the whole child, and engaging families and communities in this process, is not just a luxury for those with the opportunity and the means, or a remediation strategy for the underprivileged or underperforming. It is a necessity for all children. Genuinely pursuing an integrated, whole-child approach to education will require substantial innovation in policies and practices, but children's brain development, and the learning that depends on it, are at stake.

All of the citations for this report are available online at **http://as.pn/braindevtfootnotes.**