How Neuroscience discoveries may benefit PreK-12 education

Arthur J. Buys

Holland Professional Club

May 4, 2023

One of the questions I always have when a paper is presented at the Holland Professional Club, is what was the inspiration for studying the topic? So, let's begin with what inspired my interest in the topic. As you may recall from my paper on education funding, practically all of my family is involved in the field of education – accept my children, I raised them better! In all seriousness, I have a great respect for people who commit themselves to the field of education and find myself drawn to topics involving education – even as society's admiration and support of these public servants has seemed to diminish.

Well, that sheds some light on the education part of the presentation but what about the brain? My father was a professor who taught philosophy, logic and ethics – and for those of you how know such professors, you know they tend to be a little weird. Fortunately, the weirdness can lead to insights others may not inspire. He would periodically say, "I don't know why I am trying to teach logic to these students, it is too late." Before I learned to be careful about the questions you might ask a professor, I asked what he meant by it being "too late" to teach his students logic. He proceeded to make the case that, due to the way the brain develops and educational curriculum progresses, it would be much more productive to introduce and build critical thinking skills earlier in life. Yes, I thought there was a certain logic to that observation and have always had an interest in exploring that idea.

Since the late 1970's, when I heard my father's lament, there have been significant studies in the area of how the brain works and how we learn – much of this progress is due to incredible advances in medical technology. This field of study is broadly referred to as neuroscience, and the field includes more focused areas of study such as neurobiology, neuropsychology and cognitive neuroscience. I thought it might be helpful to show a list of research papers that have, at some level, delved into questions that are studied within the field of neuroscience. The following is the title, the researcher:

- "Humor, not just a laughing matter", Briggance, C. Larry, January 11, 2008. Humor is "the ability to both amuse and to perceive what is amusing."
- "One Day at a Time: Does AA work and if so, how?", Piers, Jim, February 2013. "Wilson designed these [12] steps to induce an intense commitment every bit as habit-forming as an addiction."
- "Technology and Our Minds in 2018", Synder, Eric, January 11, 2018. ". . . my view and perspective on technology and it's impact on our brains and society."

- "Implication of the fire/wire relationship in the brain", Van Wylen, David, October 6, 2022.
- "Visual Perception & Visual Illusion", Heusinkveld, Paul, April, 2023.

I present this representative list of papers from distinguished colleagues of the Holland Professional Club to illustrate the fascination we have with how we perceive the world around us, how we learn, how we are inspired and how we may be manipulated. It will be valuable to think back to David Van Wylen's presentation in October, because I seek to explore how a greater understand of the human brain's function may benefit our approach to educating children as they mature.

For those of us that have been parents, and especially the members of our club who have been involved in education, we are getting closer to answering the age-old question: "what is going on inside that head of yours."

These days we all carry communicators in our pockets, but this method of understanding what's going in someone's head, hasn't worked in the lab (Spock at 1:10):

https://www.youtube.com/watch?v=p_5Dt-kNgz8

The function and development of the brain is not only integrated into papers at the Holland Professional Club and Academic Institutions, but also in fictional books and movies (Young Frankenstein: Abby Normal):

https://www.youtube.com/watch?v=C9Pw0xX4DXI

"Young Frankenstein" in the laboratory may not be the best example, but I have always enjoyed the humor in that clip.

In the real world, what has been productive in the lab is mapping the brain's function by the areas of neural activity within the brain. Rather than trying to explain the process, I suspect it is more practical to share a short video about neuroimaging.

2-Minute Neuroscience: Neuroimaging

https://www.youtube.com/watch?v=N2apCx1rlIQ

These studies are not limited to brains that have the opportunity to develop on what we would consider a normal path, but also brains that have genetic variations. The challenge and the opportunity is, to apply what we are learning through discoveries in the fields of neuroscience to our approach for educating our children. Upon reviewing the information from the field of neuroscience, I am convinced that we can, to a degree, overcome the "abby normal" brain development by thoughtfully integrating our understanding about how people learn, particularly from pre-kindergarten through the adolescent years.

Before considering pre-kindergarten, it is meaningful to understand the cognitive development that occurs before a child may become part of a pre-kindergarten program.

In the first few years of life, more than 1 million new neural connections form every second (estimate from Center on the Developing Child, Harvard University). The connections that form early provide either a strong or weak foundation for the connections that form later. Adults, family and care givers are vital in the early years. I found some other short videos that I believe are a good way to more quickly understand key tools and concepts within neuroscience. This is a good overview of building the brain's "architecture".

[Experiences Build Brain Architecture - YouTube]

The interactions of genes and experience shape the developing brain. A key component in the years before pre-Kindergarten is the "serve and return" interaction between children and their parents and other caregivers. "When an infant or young child babbles, gestures, or cries, and an adult responds appropriately with eye contact, words, or a hug, neural connections are built and strengthened in the child's brain [in ways] that support the development of communication and social skills. . . . If these responses are unreliable or inappropriate—the brain's architecture does not form as expected, which can lead to disparities in learning and behavior. Ultimately, genes and experiences work together to construct brain architecture." I will pause to share another short video.

[2. Serve & Return Interaction Shapes Brain Circuitry - YouTube]

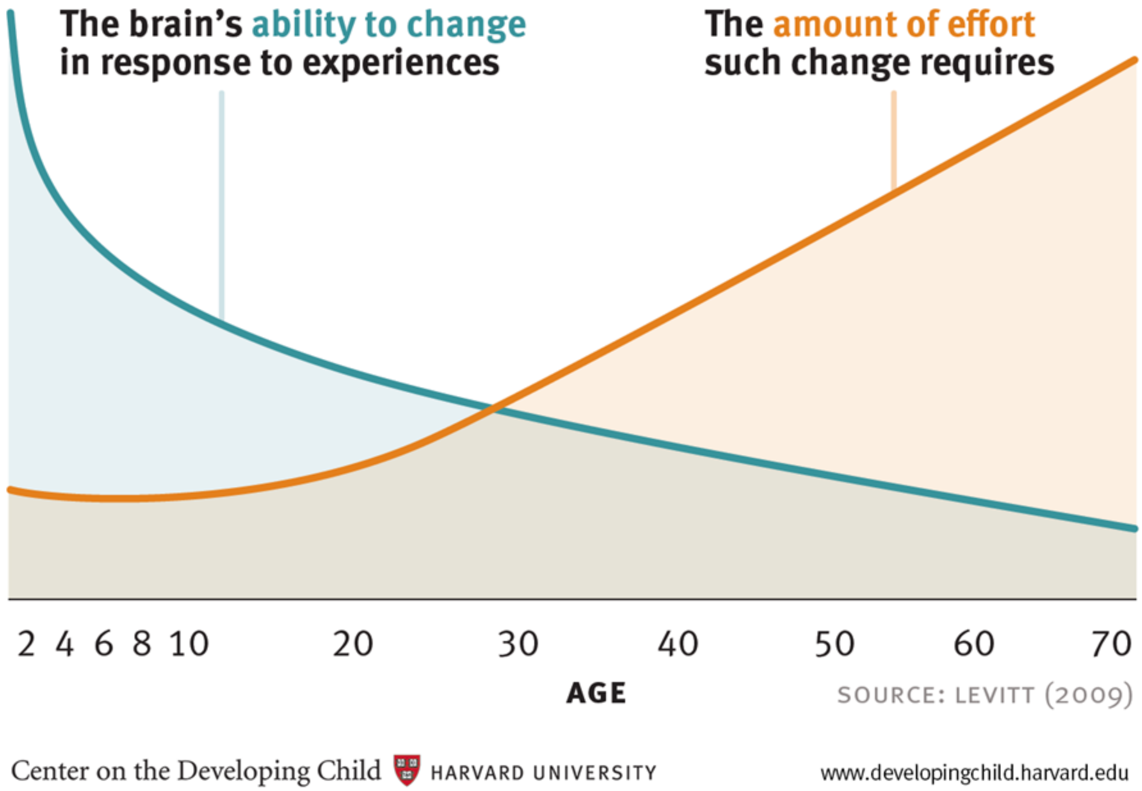
The time from birth through adolescence is vital, and the educational approach during this period is especially significant. The role of experience in these early years can greatly impact development, including development that may adapt to genetic strengths and challenges.

"The brain is the ultimate organ of adaptation. It takes in information and orchestrates complex behavioral repertoires that allow human beings to act in sometimes marvelous, sometimes terrible ways." (National Research Council (US) and Institute of Medicine (US) Committee on Integrating the Science of Early Childhood Development; Shonkoff JP, Phillips DA, editors. Washington (DC): National Academies Press (US); 2000.)

Harry Potter & the Sorcerer's Stone | Harry's Wand - YouTube (start at 3:10)

Like Young Frankenstein, the clip may not perfectly fit the topic. However, those of us that had children or grandchildren in the heyday of these books and movies, will recall that Harry Potter overcame a rough childhood, but Voldemort did not overcome the challenges rooted early in his life. "I think we must expect great things from you, Mr. Potter … After all, He Who Must Not Be Named did great things – terrible, yes, but great." Harry Potter and the Sorcerer's Stone (at 3:20)

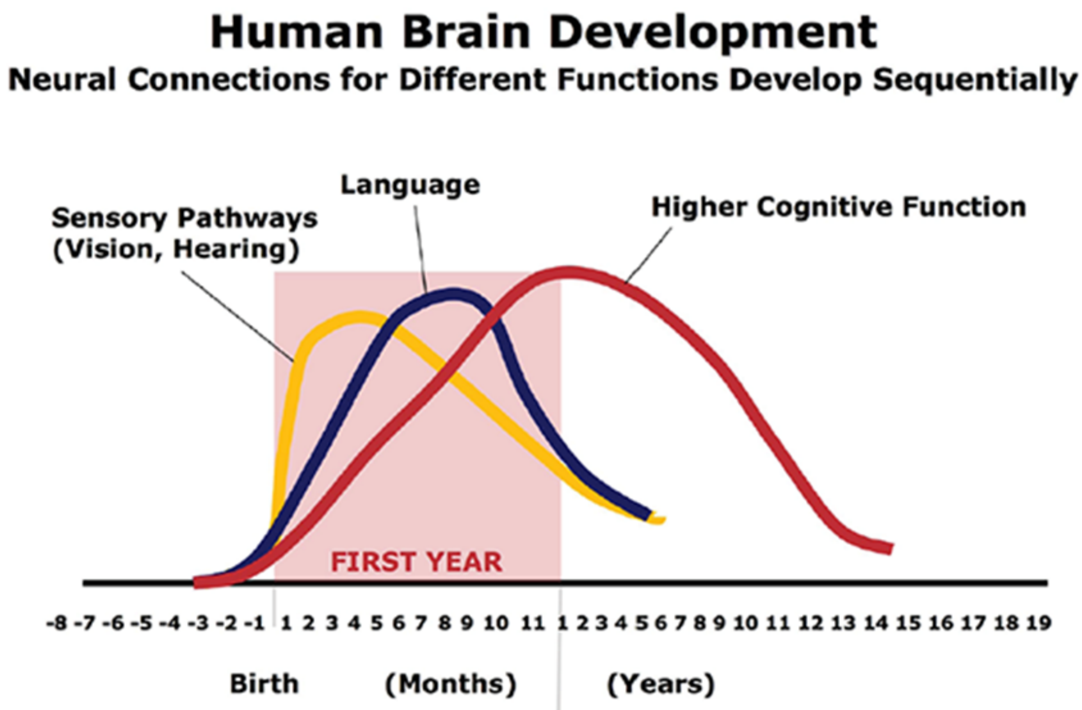
What kind of people do want, in fact need, in the world? The earliest years of life provide the greatest opportunity, and present the highest stakes, for brain develop – at home and in the education system.



How and when the brain is most capable of learning various skills, certainly varies by person and situation. One consistent observation from neuroscience research is that the more often neural pathways are used, the stronger they get. Circuits that aren't used, get weaker and disappear over time through a process known as pruning. This process is normal, but children need human interaction and a thoughtful approach to education to support the development of neural pathways for providing a solid foundation for the development of social, emotional, and cognitive capabilities.

Research in the field of neuroscience has allowed for better understanding of when the brain is most able to develop neural pathways to support various essential capabilities. The greatest opportunity to learn from experiences is heavily skewed toward the early years of life, a time where the brain has the greatest neuroplasticity. As the maturing brain becomes more specialized to assume more complex functions later in life, it is less capable of reorganizing and adapting to new or unexpected challenges.

A key question to ask is: "How should we approach education to try and take advantage of neural plasticity for building a foundation for future learning?"



In the proliferation and pruning process, simpler neural connections form first, followed by more complex circuits. The timing is genetic, but early experiences determine whether the circuits are strong or weak. Source: C.A. Nelson (2000). Credit: Center on the Developing Child.

This chart provides some perspective on when the brain is oriented to develop particular types of neural connections. Harvard researchers, and other researchers, point to a sequential pattern of brain development that is initially oriented toward developing sensory pathways, then language and finally development oriented towards higher cognitive functions. The particular age ranges in studies I found do vary, but the sequence of expected brain development over time is quite consistent.

I believe the key take-away from these discoveries is that, in the home and in the classroom, we should orient interactions and educational efforts toward foundational skills the brain is most ready to learn – and support the development of brain architecture that may be built upon over a lifetime.

Toxic Stress

Before proceeding to how discoveries in neuroscience may be applied in education, it is meaningful to mention how negative experiences may impact brain development – specifically "toxic stress". "Learning how to cope with adversity is an important part of healthy child development. When we are threatened, our bodies prepare us to respond by increasing our heart rate, blood pressure, and stress hormones, such as cortisol. . . . Toxic stress response can occur when a child experiences strong, frequent, and/or prolonged adversity—such as physical or emotional abuse, chronic neglect, caregiver substance abuse or mental illness, exposure to violence, and/or the accumulated burdens of family economic hardship. This kind of prolonged activation of the stress response systems can disrupt the development of brain architecture and other organ systems, and increase the risk for stress-related disease and cognitive impairment, well into the adult years."

3. Toxic Stress Derails Healthy Development - YouTube

Unfortunately, the situation or type of abuse that may lead to toxic stress is especially difficult to identify in the years before pre-kindergarten. Overcoming this early childhood experience may be partly addressed in early education but the home environment must also be addressed.

<u>Neuroscience and pre-Kindergarten through 12th grade education</u>

A key focus of this paper is to gain and understanding of how findings from studies in neuroscience may be, or perhaps currently are, applied within pre-Kindergarten through 12th grade education. Unfortunately, in the early 2000's integrating neuroscience discoveries into education was a bit of a craze – and this craze led to more disruption than productive application of the science into education. Neuroscience became more of a buzz-word for the marketing of products and services – and that seems to have led a bit of a backlash in the education community. Fortunately, the scientist kept working and expanding their understanding of the brain and learning, and educators continued to explore how the discoveries in neuroscience may improve the experience for children in the class and beyond.

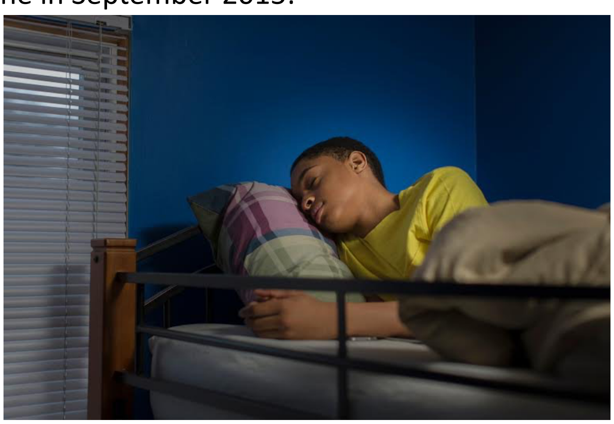
The reality is that neuroscience has reinforced some long-standing theories of how humans learn over time, and has led to new ways of understanding brain development – especially how and when we are able to learn and develop cognitive capabilities. Some educational strategies are meaningful across a broad age spectrum ("Brain based strategies for your classroom", Matthew Lynch, The Tech Advocate, June 6, 2019) and the following are some examples of strategies for the classroom:

1) <u>Physical movement</u>: Physical movement enhances instruction. Exercise oxygenates the blood that nourishes the brain. Students who move during instruction internalize their learning more quickly.
2) <u>Socialization</u>: Humans are social. We need to interact with others, and brain-based instruction includes collaborative strategies that teach how to work with others.
3) <u>Embrace differentiation</u>: Most teachers recognize that students learn differently. It's also critical to teach students that differences are normal and to develop strategies for teaching in way that recognizes that people learn differently.
4) <u>Chunk learning</u>: The human brain can process only so much information at a time. That is why breaking complex tasks down into manageable chunks facilitates learning.

Teachers know that giving process directions one step at a time helps their students focus. So does presenting information in small bites. Brain-based learning research indicates that students are more likely to remember instruction presented in segments.

5) Encourage creativity: Although schools increasingly are deleting arts programs from the curriculum, art teaches students to think in ways quite differently from sequential learning experiences.
6) Make emotional connections: The amygdala, a tiny organ in the center of the brain, stores important emotions for the brain to recall later. Emotional connections help to cement concepts in learner's minds.
7) Teach stress management: Like their teachers, students experience stress. Some stress is beneficial, like the kind that motivates us to complete an assignment or perform well on an exam. Negative stress can create distractions and impair learning. It is important for students to learn that everyone experiences stress – and it is important that they learn stress-management.
8) Study brain development: Finally, educators who learn as much as possible about the brain and how it learns are in the best position to provide brain-based learning strategies. What we already know about the relationship between neuroscience and behavioral psychology is still in its infancy. New research creates new opportunities for reaching students with brain-based teaching strategies.

It is worthwhile to take a moment for providing some examples for a few of educational strategies we just reviewed.

1) Physical Movement: There were a couple of interesting reports in the Smithsonian Magazine in September 2015:
    - 
    - In one example, it was *lack of physical movement* that was a benefit for teenagers. Research has suggested that teenagers hormonally influenced circadian rhythms are different during adolescence and they may benefit from sleeping later -- even an additional thirty minutes of sleep may positively benefit

academic performance. Cambridge University studies has supported this theory and their studies are ongoing.

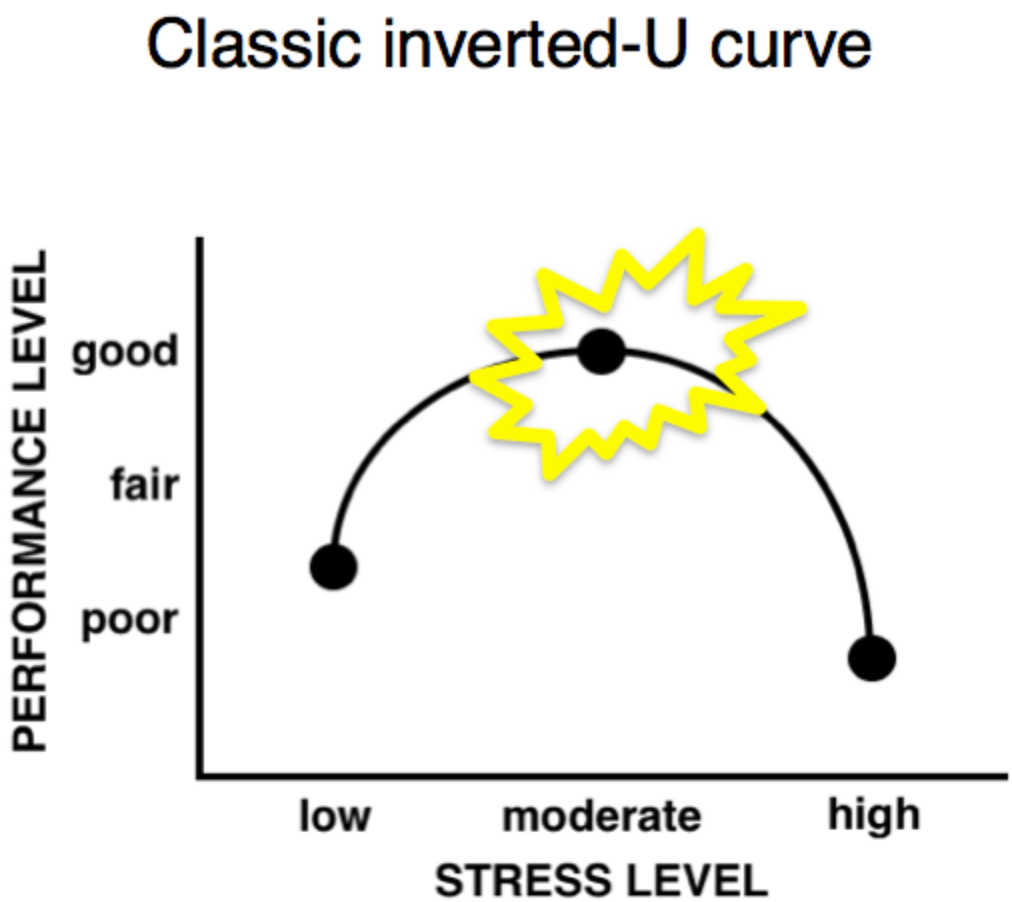
- Another example in the article relates to managing stress in students. Broadmeadows Primary School in Melbourne serves some of the Australian city's poorest families. Yet the students at Broadmeadows get higher test results than students at nearby schools with similar demographics. The program works on the principle that stressed brains don't learn well. A key component of their strategy is exercise. Students are given regular opportunities to exercise, which has also shown to help improve learning and emotional regulation. The impact on student behavior from their neuroscience oriented strategies was huge: in 2011, before the program was implemented, 96 children had to be removed from the classroom for behavioral issues. In 2012, only one student was asked to leave.

4) Chunk Learning: There is not just value in learning in segments but also how the material is presented.
   a. First we should keep in mind that the brain likes to take short cuts, just gathering and recalling enough information to perform a task. Let's test this theory with an exercise from Exploratorium: https://annex.exploratorium.edu/exhibits/common_cents/
   b. Next let's consider how information presented within a "chunk" of time may impact learning.
      i. I am going to read a series of number and ask you to try and remember as many as possible: 9 1 5 11 2 4 6 15 10 3 7 13 12 8 14. Now write down as many of the number as you can remember. Let's try this experiment on more time. Again, try to remember as many of the numbers I list as you can: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15. Now write down as many of the numbers as you can remember. Was the second time easier? In fact, the

numbers were the same in both series, it is just the way they were presented that changed.

ii. Based on new studies of how the brain deals with abstract mathematics, Stanford researchers have created a way to teach children about negative numbers. They discovered that it was much easier for people to identify the midpoint between a negative number and a positive number if the integers' distances from zero were more symmetrical (i.e., it would be easier to identify the midpoint between -6 and 8 than between -12 and 3). Introducing the concept in a way that allow students to take advantage of their natural sense of symmetry, sets them on a path to better solve the problems that little or no symmetry.

7) Teach stress management: Stress and performance are related in an "inverted U curve" (see diagram). Stimulation to learn requires a moderate amount of stress (as measured by the level of cortisol which influences brain activity). A low degree of stress is associated with low performance, as is high stress, which can set the system into fight-or-flight mode so there is less brain activity in the cortical areas where higher-level learning happens. Moderate stress can be introduced in many ways: by playing unfamiliar music before class, for example, or changing up the format of discussion, or introducing any learning activity that requires individual participation or movement. The challenge in a classroom setting is an individual's production of cortisol in response to an event varies. ("Neuroscience and how students learn", Daniela Kaufer, associate professor in the Department of Integrative Biology, for the GSI Teaching & Research Center's How Students Learn series in Spring 2011) UC Berkley) http://gsi.berkeley.edu/media/kaufer-inverted-u-curve.png



I found serval compelling observations from the field of neuroscience that stood-out to me and did not neatly fit into the presentation. I thought it best to share them directly rather than try to categorize the observation or omit the from the presentation:

- "It turns out that strengthening a synapse cannot produce a memory on its own, except for the most elementary reflexes in simple circuits. Vast changes throughout the expanse of the brain are necessary to create a coherent memory. Whether you are recalling last night's conversation with dinner guests or using an acquired skill such as riding a bike, the activity of millions of neurons in many different regions of your brain must become linked to produce a coherent memory that interweaves emotions, sights, sounds, smells, event sequences and other stored experiences." ("The brain learns in unexpected ways", R. Douglas Fields, Scientific American, March 1, 2020)
- "One of the most fundamental scientific principles is 'trial and error'. It is essential for any scientific progress." Only by being allowed to make mistakes can we learn from ourselves and get better. Yet schools are not geared to helping students learn from their mistakes, but rather to condemning them. (Thomas Mohrs, an education scientist at the

University of Education, Upper Austria (PHOÖ), in Linz, The UNESCO Courier, January 2022)
- "For years, the teenage brain was seen by researchers, policymakers, and the public as more of a burden than an asset. Adolescents were risk machines who lacked the decision-making powers of a fully developed prefrontal cortex—and liable to harm themselves and others as a result. That narrative is beginning to change. There is growing recognition that what was previously had seen as immaturity is actually a cognitive, behavioral, and neurological flexibility that allows teens to explore and adapt to their shifting inner and outer worlds." ("What neuroscience tells us about the teenage brain", Zara Abrams, American Psychological Association, August 25, 2022)

Current research is another topic I felt would meaningful to share. There are ongoing studies designed to broaden our understanding of how neuroscience may benefit educational efforts. I have listed some examples:

- The Adolescent Brain Cognitive Development℠ Study (ABCD Study®) is a $290 million study funded by the National Institute for Health. The study began late in 2018 and the goal is to "increase our understanding of environmental, social, genetic, and other biological factors that affect brain and cognitive development that can enhance or disrupt a young person's life trajectory."
- The National Institute for Health's "Blueprint for Neuroscience Research" has two components:
    - NIH Human Connectome Project "is an ambitious effort to map the neural pathways that underlie human brain function. The overarching purpose of the Project is to acquire and share data about the structural and functional connectivity of the human brain.
    - NIH Blueprint Neurotherapeutics Network (BPN) "was launched to enable neuroscientists in academia and biotechnology companies to develop new drugs for nervous system disorders. The BPN provides funding for small molecule drug discovery and development, from hit-to-lead chemistry through phase I clinical testing.
- The HEALthy Brain and Child Development Study (HBCD) "will recruit a large cohort of pregnant women from regions of the country significantly affected by the opioid crisis and follow them and their children through early childhood." In 2021, "scientists began collecting a large, well-characterized dataset [in over 25 sites across the country] that captures biologic, brain, behavior and social information about the children and their families, that will enable comparisons of brain development and behavioral outcomes of young children from a variety of environments."
- I also came across an interesting article about how technology in the area of neuroscience is advancing titled, "A focused approach to imaging neural activity in the brain", Anne Trafton, MIT News, June 26, 2020). "When neurons fire an electrical

impulse, they also experience a surge of calcium ions. By measuring those surges, researchers can indirectly monitor neuron activity, helping them to study the role of individual neurons in many different brain functions. One drawback to this technique is the crosstalk generated by the axons and dendrites that extend from neighboring neurons, which makes it harder to get a distinctive signal from the neuron being studied. MIT engineers have now developed a way to overcome that issue, by creating calcium indicators, or sensors, that accumulate only in the body of a single neuron."

One of the challenges for this paper was finding a study that is ongoing and is improving our understanding of how neuroscience may inform and benefit educational efforts. Fortunately, I found an ongoing study and will wrap-up my presentation with some findings from this effort. There is a school in Menlo Park, California that is working with Stanford University neuroscientists. The scientist are working with teachers and students from an onsite research lab, the Brainwave Learning Center at the Synapse School (yes, that really is the name of the school).

Stanford's Brainwave Learning Center at the Synapse School

"By being embedded in a school, we can really see how school experiences impact the development of systems like the brain circuitry for reading or the brain circuitry for computing numbers," said Stanford Graduate School of Education (GSE) Professor Bruce McCandliss, who leads the project. The Brainwave Learning Center is part of the broader Educational Neuroscience Initiative at the GSE that explores how changes in the brain's neurocircuitry support emerging skills that are foundational to education such as reading, math and attention. Researchers want to know how and why particular interventions benefit some learners and not others, and create new approaches that improve the educational experience for all students.

"When children go off to school, they need to adapt the circuits of their brains in new and profound ways as they learn how to translate letters into words, words into ideas, and numbers into mathematical concepts." The following are some compelling observations from the program at the Synapse School, to date:

- Stanford research combine brain measurements with leading behavioral reading assessments. The aim is to leverage the overlapping and complementary insights of these approaches to better understand the interaction between educational experiences and an individual student's strengths and vulnerabilities, and to predict and rapidly respond to emerging challenges with students.
- Each student brings with them a diversity of developing skills in language, vision, attention, and other cognitive factors that can be readily measured on-site in the Brainwave Recording Studio. The students have a regularly scheduled visit to scan their brainwaves every 6 months. Additionally, the students may be involved in special projects and visit the Brainwave Learning Center for those studies.

- A key benefit of the on-site program is allowing students to watch live computer displays of their brainwaves and witness how their own brain waves change as they concentrate on a task or engage in mindfulness. “This interactive experience provides each child the chance to see and think about their own brain activity, how it changes with learning, and even how it changes with moment-to-moment shifts in mindset, which helps instill in students a sense of ownership of their learning process.”
- Researchers at Stanford will be able to compare their results with a study which began in 2019 that includes over 11,000 third grade children. The study completed an extensive brain scanning protocol in multiple cities across the country. “Each student has pledged to repeat the scans every two years as they progress through elementary, middle, and high school, providing the largest brain development study ever carried out and enabling researchers to follow changes in the structure and functions of specific neural circuits and fully explore the diversity of paths that children’s brain development takes.”
- In a test related to language, two different sets of learning instructions either biased students toward a “whole-word” strategy or a “letter-sound” strategy. Words learned under whole-word instructions produced a pattern of brain activity associated with novice learners or unfamiliar words. In contrast, words learned under letter-sound instructions produced a left hemisphere response in regions associated with adult-level word recognition. This adds to a growing body of work suggesting that with their instructional choices, teachers can play a significant role in helping to direct learning, which may have an impact on which brain circuits are changing as a result.”
- In a mathematics related test, some children’s early difficulties with ordering or combining sets of objects, recognizing spatial patterns, and understanding quantities, correlate with later math achievement. Recognition of this correlation may help educators design extra support for a young learner to strengthen the brain network that underlies math skills.
- “Around the world, there is a growing number of collaborations between cognitive neuroscientists and schools that are beginning to tackle a large set of issues beyond just reading and mathematics. This work will help us understand how critical factors such as empathy, creativity, self-control, and problem solving develop in school experiences and how schools can influence the brain circuits involved in much of what makes us human.”

As I shared, some people got ahead of themselves in early 2000’s, ahead of the science, as they tried to apply brain scan related studies in the classroom. Nevertheless, tremendous resources and time continues to be invested in finding practical ways to improve educational outcomes for students using discoveries from field of neuroscience.

The video is of an experiment that I hope, after today's presentation on neuroscience and education, we will recognize as taking place in a high stakes period for brain development. It is known as the "Still face experiment".
Still Face Experiment Dr Edward Tronick - YouTube