Maximizing Student Learning and Success : Explicitly Teaching Neuroplasticity and Learner Mindsets

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学習者の学習能力と達成感を最大限に導く：マインドセットで脳の可塑性を高める教授法

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Abstract :

Over the past few decades, thanks largely in part to improvements in brain-imaging technology, the field of neuroscience has made enormous progress in our knowledge of how the brain works and how we learn. Only recently, however, have such research results from neuroscience gradually begun to trickle down to the domain of education and be incorporated by teachers in actual classroom learning. Drawing from recent research in this field, this paper will discuss two key concepts that are crucial for both students and educators alike to understand in order to maximize student learning, motivation and confidence― brain plasticity, and fixed and growth learner mindsets.

要旨：ここ数十年の間に、脳画像技術の向上により神経科学の分野は、脳機能や学習に関する私たちの知識に著しい進歩をもたらした。しかし、神経科学のそうした研究成果が教育の領域に及んだり、教師によって実際の授業に取り入れられ始めたのはごく最近のことである。こうした領域の最近の研究成果に依拠して本論文では、学習、動機付け、自信を最大化するために学生並びに教師の両者にとって重要となる２つのキーとなる概念を論じるものである。その２つの概念とは、脳の可塑性と固定・成長という学習者のマインドセットである。

Key words : Neuroscience, Plasticity, Mindsets, Brain, Praise

Introduction

Neuroscience is the study of our brain, nervous system, and all its complicated and diverse functions. Over the past few decades, thanks largely in part to improvements in brain-imaging technology, the field of neuroscience has made enormous progress in our knowledge of how the brain works and how we learn.

Only recently, however, have the findings from neuroscience gradually begun to trickle down to the domain of education, and actually begun to be incorporated by educators in classrooms. In addition, our image and understanding of what human intelligence is and how it develops has been

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changing as well, and new research is showing that how we thought and taught in the past may not actually be ideal for our student's success, our own teaching, and how we think of learning.

This paper will discuss two areas that are critical for both teachers and students to understand—brain plasticity and lifelong learning, and two kinds of learning mindsets, fixed and growth. Without a solid understanding of these we're limiting our students' potential and fostering an environment that may be counter-productive and inefficient for maximized learning.

Part 1 : Neuroplasticity & Lifelong Learning

Not so long ago, most people believed that our brains (and thus intelligence) did not change after childhood, that it was 'hard-wired' and 'fixed' by the time we became adolescents or adults. However, recent research has shown this is not true—that in fact, our brain is adaptable and malleable like plastic, hence the coined term, 'neuroplasticity.' Certain experiences and environmental input cause new connections to form or strengthen, making the brain smarter by literally 'rewiring' it. Furthermore, the good news is this isn't true just for young children or adolescents— neuroplasticity can continue throughout our entire lives, provided it gets the necessary requirements to do so (Sousa, D., 2010).

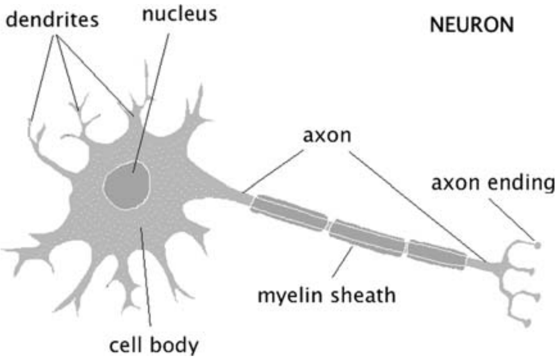
How we learn : The brain and neurons in a nutshell

Humans have around 23 billion cells in our brain called neurons. They make up around a quadrillion (10^{15}) connections amongst themselves, sending signals to and from the brain at up to 200 mph. It is their strength, number, and location which affect how our brains work.

A neuron has three main parts— the body (or soma), with branches called dendrites (signal receivers), and an axon (signal producer/transmitter) (Figure 1). Each neuron acts like a mini relay station or dam. In Step 1, a neuron receives information (electrically-chemically) from other neurons, via its branchlike dendrites. This information is processed in the neuron's nucleus (center). It is here that the dam or relay station decision is made. Certain requirements need to be met to make a nucleus 'excited' by the information. If the nucleus does not get 'excited' from the received information, nothing else will happen and this particular information flow will stop here.

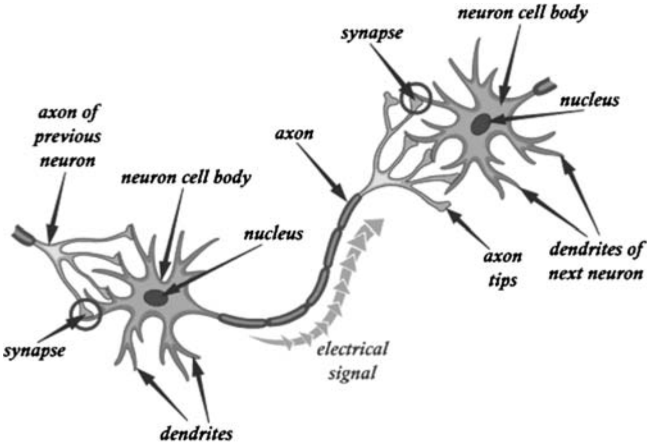
However, if it does get 'excited,' Step 2 begins. Step 2 involves the nucleus passing the information along to its final part, the axon, which is a long extension that attempts to transmit the infor-

Figure 1



http : //www.brainleadersandlearners.com/general/plasticitys-pathways-to-innovation/ [Accessed 10 December 2016] mation (as an electro-chemical signal) to other connecting neurons (the axon 'acts on' other neurons). The axon is covered and insulated by something called the 'myelin coat,' which affects the transmission speed of the information. The more myelin insulation there is, the quicker the information can travel to the end of the axon (and over to the next neuron(s)). (Figure 2)

Figure 2



https : //blog.bufferapp.com/why-practice-actually-makes-perfect-how-to-rewire-your-brain-for-better-performance [Accessed 10 December 2016]

The key takeaway for educators and students from this is that axons become better insulated (myelination) with heavy usage. This means often-used networks of neurons have faster response times if and because they are frequently used, which is the core of learning. Thus learning is essentially the establishing of new neural networks. It is the density of the brain, as measured by the number of connections that distinguishes greater from lesser mental capacity (Howard, 2006). Our billions of neurons connect and interconnect with thousands of other neurons, creating quadrillions of neural networks, which light up every time we think, feel or do something. Well-traveled pathways become our habits and established ways of thinking, feeling and doing.

This is the science behind oft-cited English phrases such as "practice makes perfect" and "use it or lose it." Our learned skills improve and get smoother over time because we have activated those neuron pathways so often they have become heavily insulated, stronger, and more efficient. Things that used to be hard then become easier and easier. This process is similar to a small path in the forest that becomes wider and easier to travel on the more people have walked over it. Likewise, pathways we don't use very often end up becoming pruned (cut away) or weakened, because resources are diverted to other (more often-used) pathways instead. In this case, the forest path has become overgrown with weeds and plants and is now difficult to traverse due to no one having traveled it for too long a time.

Understanding this process also helps explains the phrase "old habits die hard." Often-used pathways make for stronger connections, but this can make things difficult for us if the pathway is an old (bad) habit. The old habits are well insulated networks, so they often easily win out over newer competing networks. This is why it is often so difficult for us to make a major change in our lives once we become adults, or if we have been doing something a certain way for a long time.

This process of rewiring our brain by forming new connections and weakening old ones is neuroplasticity. The good news, as the next section will explain, is that we can always start creating new roads―and if we travel them more and more, eventually we will bring about improved learning, efficiency, or new ways of thinking, feeling, or doing something (ex. new habits).

Neuron connection growth phases—infancy, puberty and beyond

The quadrillions of neural connections, or networks, are at the heart of our intelligence, our abilities, and the ease and speed with which we can do activities. Many people believe that infancy is the best (and only) time to learn, especially for things like languages, physical activities like sports or figure skating, or coordination activities like playing a music instrument or dance. In some ways this is still true, but in many other ways research has shown it is not (Howard, P., 2006).

When babies are born, their brains have about the same number of connections as adults. However, these connections increase at an amazing rate, so that by the time children are three years old, the connections in specific regions of their brains have doubled or even tripled. It is for this reason that infants are often compared to sponges―like a sponge with water, infants are able to absorb and learn information incredibly quickly and easily during this time because their neural networks are still incredibly malleable and easily changeable. This doubling and tripling of neural networks doesn't last too long though. The brain soon undergoes a process called 'pruning,' in which it goes through its neural networks (pathways) and cuts away (prunes) the unused or unnecessary one to allow for the often used pathways to grow bigger and stronger, and to make room for new learning (new pathways). By the time children are eight or so, they're back to their adult numbers.

Yet the brain isn't finished developing yet. Once again at puberty, the whole process starts over again in different regions of the brain. Again, there is frenetic neural growth and pruning back. "While excess capacity is being shed, the myelin sheath that protects the axon continually thickens, thus increasing safety, permanence, and speed of the axon's transmission. Thus we simultaneously lose capacity and gain efficiency. (Howard, P., 2006)." It isn't until around the time students prepare to enter university that their brains begin to settle down to their adult forms. But even then things aren't over. "While the biggest construction programs in our brains are finished by around our early 20s, fine-tuning continues well into our mid-40s." (Medina, 2008). The key takeaway from this is that research has shown that our brain continues to make new neurons throughout our life in response to mental activity, and cognitive function can be improved, regardless of age. Thus adolescent or adult, no one should believe that they are trapped in their current levels of intelligence/ability for the rest of their lives.

Our brain development is often compared to working out a muscle―the more activity you do, the larger and more complex it can become. However, just like how we grow stronger by straining our muscles and pushing ourselves to our limits, our brain improves and strengthens, not by doing things that we know well or that comes easily to us, but from new and difficult things, things we struggle with that stretch us. Our muscles rebuild themselves to become stronger, and our brain's neural networks rewire themselves to become more interconnected, faster and efficient. "Intelligence can be considered as a measure of students' ability to make accurate connections between new input and existing patterns of stored information. . . . The more experiences they have, the more likely their brains will find a fit when comparing new experiences with previous ones. These connections allow them to acquire and apply the new knowledge to solve problems. Through practice, experience, and mental manipulation, the brain builds intelligence (more accurate predictions) by extending, correcting, and strengthening neural networks" (Willis, 2010). Our intelligence and skill at doing something is a result of the efficiency and interconnectedness of our neural network.

Over the past few decades a multitude of research studies supporting this have come out, showing how the brain physically changes, and how more neurons develop from new or challenging exertion. To briefly highlight a few :

In Draganski, Bogdan, et al. (2004), subjects in their 20s were taught to juggle. After only three months, brain-imaging scans showed physical differences in their brain—the people who learned how to juggle increased the amount of gray matter in their occipital lobes (visual memory areas), showing the brain's plasticity to accommodate for the new skill set. But when they stopped practicing the juggling, the new gray matter vanished. In Maguire, Eleanor A., et al. (2000), their study on London tax drivers showed that doing something challenging can cause physical changes in the brain. To be a taxi driver in London you need to pass a very challenging exam of the streets of London which often takes years to master. They found (using brain MRI's of taxi drivers and non-taxi drivers) that the part of the brain responsible for spatial memory, the hippocampus, was larger and heavier in those of the taxi-drivers than non-taxi drivers. Lastly, in Ickes et al (2000), and Guzowski et al. (2001), researchers took one group of rats and put them each into a no-stimuli, empty cage environment, while another group of rats were put together with other rats in stimulating cages with puzzles. At the end of the experiment, they examined the brains of each group of rats. The rats who were put in the challenging environment with mazes and other rats had much denser, more interconnected brains, and their brains weighed more. After being tested they were actually smarter and better at solving problems and learning new things.

An understanding of the brain's neuroplasticity has huge implications for both student learning and our own teaching, which the next section will explain.

Part 2 : Connecting Neuroplasticity to Teaching and Learning : Fixed and Growth Mindsets

The purpose of the prior section was to show that our brains are plastic and can always change or be improved. Yet despite such research findings, many people today still believe that one's abilities and intelligence are largely decided at birth or from our genes—we believe we're either naturally talented at music or sports, or we're not ; either inherently good at math or science, or doomed to always struggle and just get by. We also tend to grow up believing that the Michael Jordans, Walt Disneys, Beethovens, Einsteins, and other geniuses and sports stars of the world were born talented, and became successful effortlessly.

However, almost always this isn't true—the above names and many others have failed, and failed often. What they didn't do was give up, but instead reapplied themselves and learned how to improve from their mistakes in order to achieve their goals. "Children, as well as many adults, mistakenly think that intelligence is determined at or before birth by their genes and that their effort will not significantly change their potential for academic success. Especially for students who believe they are "not smart," the realization that they can literally change their brains through study and review strategies is empowering" (Willis, 2010).

This section will discuss learner mindsets, and how research on teaching interventions on this subject have been shown to cause a paradigm shift in student learning, motivation and self-confidence.

In her groundbreaking book *Mindset* (2006), Carol Dweck explains that people generally fall into one of two categories about how they think of skills and intelligence―a fixed mindset, or a growth mindset. Which of these mindsets one has leads to enormous ramifications to one's approach to learning, making mistakes, social interaction and most aspects of life in general.

Those with a fixed mindset believe that intelligence and ability is an innate and fixed trait, like one's eye color or height, and there isn't much that can be done to change it. They often think that real success comes without effort, because if you are truly smart or good at something it should come easily and effortlessly. Additionally, since everything is fixed, they often feel the need to prove themselves to others, to show that they are not deficient. If they are to be judged (for example, through testing) they don't want to be found lacking. This leads to their belief that mistakes are something to be feared and hidden from others, because they show that you aren't good enough or are a failure.

The opposite of the fixed mindset is the growth mindset―those who believe that intelligence isn't fixed or set in stone at birth, but can be developed, similar to becoming stronger by straining and working out your muscles at the gym. Growth mindset people believe that "your basic qualities are things you can cultivate through your efforts. Although people may differ in every which way― in their initial talents and aptitudes, interests, or temperaments―everyone can change and grow through application and experience" (Dweck, 2006).

Even from this brief description of these two mindsets it's easy to see how the growth mindset would foster a stronger passion for learning than the fixed mindset. "Why waste time proving over and over how great you are, when you could be getting better? Why hide deficiencies instead of overcoming them? And why seek out the tried and true, instead of experiences that will stretch you? . . . This is the mindset that allows people to thrive during some of the most challenging times in their lives" (Dweck, 2006). Studies have shown that students with a growth mindset do better in school than those with the fixed mindset, partly because they approach learning differently and have different underlying goals. Students with a growth mindset aren't afraid of making mistakes, because they value and seek feedback. Feedback is the only way to learn about their strengths, but even more importantly, their weaknesses as well. Knowing these, they can continue to grow and develop, and the main way to do this is through learning new things.

So students with a growth mindset will ask questions when they don't understand something because they are aware that that is how they learn, while students with the fixed mindset are more focused on trying to either show how smart they are or trying not to draw attention to their lack of understanding.

In addition, students with a fixed mindset view effort negatively. They believe if they have to try hard they must not be very smart. However, those with a growth mindset view effort as the way that you learn, the way that you *get* smarter. Finally, the biggest area of difference between students with each of these mindsets is when they are faced with a challenge or setback. "Students with a fixed mindset will give up because they think their setback means they're not smart, but students with a growth mindset actually like challenges. If they already knew how to do something, it wouldn’t be an opportunity to learn, to develop their intelligence. Given that students with a growth mindset try harder in school, especially in the face of a challenge, it’s no surprise that they do better in school” (Blackwell et al., 2007). Students who believe intelligence is malleable are more likely to value learning, believe in effort, and show more resilient reactions to setbacks. (Figure 3)

Figure 3

So how does this affect us as teachers? “A great positivity-building tool comes from students’ learning about their brain’s ability to change through this neuroplasticity process. When students understand that their brains can develop stronger, more efficient, accessible, and durable neural networks through their actions, they have the positivity, resilience, and motivation to do their part to develop the skills, knowledge, and intelligence to achieve their goals” (Willis, 2010). Various studies on explicitly teaching students about their brain and the growth mindset have shown amazing results regarding improved student academic performance.

To highlight just a few :

Nussbaum & Dweck (2008) were interested in the kind of feedback people would seek out after they struggled. In the first part of their study, they primed one group of undergraduate participants to have a fixed mindset, and another to have a growth mindset. Afterwards they purposely gave them a difficult test and told the participants that they hadn’t done well on it. They then gave them a choice. The undergraduates could either look at the tests of people who had done worse than them on the test, or the tests of people who had done better than them. People primed to the growth mindset chose people who had done better than them in order to fix their mistakes and learn from them, but people primed to the fixed mindset more interested in making themselves feel better, and instead chose to look at the tests of people who had done worse. This study showed how the mindset one has can effect motivation to improve oneself and lifelong learning.

In Jones (2009), a study of adolescent students showed that those who thought of intelligence as malleable (plastic) were more likely to receive higher grades, whereas students with a fixed mindset of intelligence did worse in school performance. In the same study, the authors implemented an intervention with low-achieving teenagers about the structure and function of their brain, how learning changes the brain by producing new neuronal connections, and provided the clear message that the pupils themselves were in charge of this process. This led to a positive change in classroom motivation, and grades improved compared to the control group of students who had not received the intervention.

Paunesku et al. (2015) showed that when students learn about the brain and its plasticity they do better in school. In their study with middle school students, they taught students a growth mindset through a neuroscience lesson. Compared to the control group, their study showed that students who believed that intelligence could be developed earned significantly higher grades and were more likely to move to advanced math courses over time.

Mindsets have also been shown to predict who takes more advanced courses. In a study with middle school students, those with a growth mindset were more likely to be placed into advanced math over time. And recently several large scale studies have shown the relationship between mindsets and achievement in whole countries and even in multiple countries. Lastly, researchers at Stanford University PERTS have been creating online programs that teach students how the brain gets stronger. Underperforming high school students who participated in a PERTS online growth mindset program had significantly higher GPAs and passed more courses than students in a controlled condition (Romero et al., 2014).

What's so promising and exciting is that if these kind of positive results occurred when participants were only briefly primed to think in a growth mindset. Imagine the impact that teachers can have through teaching and reinforcing a growth mindset during an entire semester or academic year, or if parents emphasize this during a child's entire childhood. Such studies show that students who adopt a growth mindset do much better in school, and are more likely to have a passion for learning and become lifelong learners. "Academic-mind-set interventions target students' core beliefs about school and learning… In so doing, they can change how students interpret and respond to challenges in school, increase students' resilience, and set in motion positive recursive cycles that increase success over time" (Garcia & Cohen, 2012 ; Paunesku, et. al, 2015 ; Yeager & Walton, 2011).

Part 3 : Feedback & Praise

The final key to successfully teaching and reinforcing neuroplasticity and growth mindset has to do with praise. As educators (or parents), without realizing or intending to do so, we often promote the fixed mindset through our praise. Our intuition is to laud students for being smart and for their positive abilities. However, research has shown this sends the wrong message.

Temple University psychologist Elizabeth Gunderson studied the effects of two different kinds of praise on 53 toddlers. The first kind of praise focused on their ability, and included phrases like "You are really a smart kid!" "How talented you are!" and "You are smart at that, aren't you?" The other kind of praise focused on a child's effort, and included such phrases as "You worked hard on that!" and "You really stuck with that one!" Follow-up studies revealed that the toddlers who received praise aimed at their effort were more persistent at sticking with problems, while those kids receiving ability-oriented praise gave up more quickly on such tasks (Gunderson, E.A., et. al., 2013).

Gunderson related this phenomenon to Carol Dweck's notion of fixed versus growth mindset, with people having a fixed mindset thinking they are as able as they will ever be, while those with a growth mindset thinking there is no known or fixed limit as to what they are capable of. The praise aimed at reinforcing a child's effort results in more resolve and determination in the child, while ability praise actually can discourage a child from trying harder because they think that more effort will not increase their ability.

In another study, this time with fifth graders, researchers asked the students to complete a set of moderately challenging problems, then told all students that they did well and had gotten a good score. For one-third of students, the feedback stopped there, but for another third of students, they were given intelligence praise. In addition to, "Wow, that's a really good score," they were also told, "You must be smart at this." The final third of students were instead given effort praise. In addition to, "Wow, that's a really good score," they were told, "You must have tried really hard." After students received feedback for their high scores, they were all given a more challenging set of problems, and after that, were given one final set of problems equal in difficulty to the first set. The 1/3 of students who had received the effort praise ("You must have tried really hard") did better on the final set of problems, while the 1/3 of students who had been given intelligence praise ("You must be smart at this") actually did worse. Just one line of praise significantly impacted students' performance (Mueller, C. M., & Dweck, C. S., 1998). Therefore instructors should strive to use effort-praise over ability-praise as much as possible.

Conclusion : Practical Advice and Takeaways

As this paper has shown, explicitly teaching students about neuroplasticity and learner mindsets can lead to improved student learning, motivation, perseverance, and self-confidence. In order to take advantage of such benefits, teachers should :

1. Teach students the basics about how their brains work, how we learn, and how to improve (neurons, brain plasticity, neural networks, the brain is like a muscle, etc.)
2. Teach students about fixed and growth mindsets
3. Foster a growth mindset environment by giving immediate, constructive feedback, and praising effort, not ability (see Appendix A for some examples). This implies the value of hard work, and that hard work is the cause of success. This also may help get students focused on learning, rather than simply doing an activity for the sake of just getting a good score or grade.
4. Teach students to give up perfectionism, and celebrate mistakes as the norm. Stop insisting in your class everything has to perfect, and don't be disappointed when it isn't. Explain and apologize to students if they got a perfect score on an activity and say you're not challenging them enough if they don't make mistakes while learning, helping them learn, etc.) "Humans aren't perfect and neither is the process of learning. You'll experience winding courses, make many mistakes, and do bad work whenever you set yourself to learn. Stop insisting that your endeavors all be perfect. Just aim for doing better each time and excellence will find you all by itself" (Edudetic, 2014).
5. Work on trying to get students to take their ego out of learning and just focus on the task at hand. Teach through example that they shouldn't compare themselves with others, that eve-

ryone learns and develops at different rates and in different areas. Their only goal should be self-improvement from past activity.

By utilizing these strategies, we can harness our students' potential and foster an efficient environment for maximized learning.

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Appendix

Appendix A

Effort-Praise vs. Ability Praise Examples

Instead of This (Person-Praise)	Try This (Process-Praise)
Great job! You must be smart at this.	Great job! You must have worked really hard.
See, you *are* good at English. You got an A on your last test.	You really studied for your English test and your improvement shows it.
You got it! I told you that you were smart.	I like the way you tried all kinds of strategies on that math problem until you finally got it.
You are such a good student!	I love the way you stayed at your desk, you kept your concentration, and you kept on working. That’s great!