Understanding Neuroscience to Improve Education

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Education relies on the ability to continually learn and has often been considered a social science rather than a physical science. Advances in neuroscience now allow us to approach learning and intelligence from a scientific standpoint. There is a persistent problem of unequal access to quality education as well as broad social issues that stem from not having a solid education to grow from. In order to provide a conceptually solid attempt to the solution, I work to apply our understanding of cognitive science to this social issue. I conducted research in the anatomy of intelligence, cognitive functions related to intelligence, if these measures are malleable, and how to manipulate these characteristics – as well as social trends to connect the science to. I found that the cognitive function Working Memory is a major function in mediating intelligence levels by serving to keep track of what is presented. Furthermore, I found that there are indeed structural elements of our brain that mediate intelligence which are heavily affected by learning during our maturational years by establishing and saturating the neuronal connections in our brain. Additionally I found that intelligence levels are impeded by low quality education. These results lend to the idea that cognitive training can be utilized in the classroom to boost performance. In addition, the results are really complementary as there is scientific evidence that links low quality education to certain lifestyles. This is not the ultimate solution to solve America’s education issue, but there is a grave problem that is unfair to many people and detrimental to society. However, the connections and results can serve as a starting point of the solution or even as an impetus for more research and for action put towards the problem.

Utilizing an understanding of the neuroscience behind intelligence can drive a solution that aims to alleviate the broad detrimental effects of low quality education. Specifically, Working Memory (WM) is a cognitive function that can be utilized to boost performance and drive lifestyle improvements. High school dropouts are costly to a society because they can become a strain on social and economic systems. Dropouts have a higher tendency to gravitate towards crime which presents an issue on the social side. Additionally, dropouts also tend to have low-income jobs that do not contribute to the economy much and can drain the government through aid programs such as welfare. One cause that drives dropout rates is a low self-perception of academic ability. This is interesting as dropout rates are significantly higher in areas that have low socio-economic standards (SES) in conjunction with the finding low quality education inhibits intellectual fulfillment. This shows that many people are held back in their lives because of the education they are given and demands serious consideration of how to change this. Given our understanding of cognitive science, it will prove invaluable to consider the neuroscience behind intelligence when addressing the issue of education. Such as by evaluating certain cognitive tasks in regards to their effects on and connections to intelligence, and if these tasks can be trained and improved. Furthermore, considering the actual anatomy behind intelligence can prove useful as a test for evaluating certain methods of learning as well as a guide for how to teach.

**Poor Academic Performance: Societal Detrments**

Quality primary education has long been viewed as a common requirement for economic mobility and for access to respectable lifestyles and employment. Despite this commonly held belief that education is essentially a necessity, there still exists a large discrepancy in availability of quality education which is not only undemocratic to those affected, but also in turn detrimental to both society and the economy.

“High school dropouts are three and one-half times more likely than high school graduates to be arrested, and more than eight times as likely to be incarcerated. Throughout the country, 68 percent of state prison inmates have not received a high school diploma” (Christeson et al, 2008). Furthermore, the negative effects of high school drop out rates seep into the economy as dropouts pay less taxes, earn less, are more likely to take advantage of draining government programs such as welfare, and are much more likely to engage in criminal activities. To exemplify the detrimental effects of unfinished education, “if Washington could raise male graduation rates by 10 percent, the state would save approximately $221 million dollars every year, including almost $100 million in reduced crime costs alone” (Christeson et al 2008). Accordingly, high school graduates earn more than three hundred thousand dollars more on average than drop outs over the course of their professional life – until age 65 (Monrad 2007). This not only exemplifies the benefits on the economy, but also illustrates the significant lifestyle improvement that can be achieved by providing quality education for areas with low SES conditions.

Based off the evidence that improving education can alleviate many of the persistent problems that are festering in our current society, it is shocking that there is not a stronger focus on solving this problem. Essentially, in addition to broadly distributing quality education as a sort of human right and

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democratic or moralistic ideal, it makes sense in terms of both safety as well as in a more qualitative view in light of the previously mentioned potential benefits on the economy. Better education does indeed have significant benefits as children who participated in the Perry Preschool program – a high quality educational program for at risk youth - and other at risk children who did not were compared with the conclusion that “children enrolled in the program were 44 percent more likely to graduate from high school than similar children randomly assigned to not participate in the program. A separate analysis concluded that the Perry Preschool Program would yield 19 extra high school graduates for every 100 students provided the intervention” (Christeson et al 2008). It is evident that the issue lies concentrated in certain areas based off of the finding that “about 12 percent of American high schools produce more than half of the nation’s dropouts” and that “a student within the age range of sixteen to twenty-four years old who comes from the lowest quartile of family income is about seven times more likely to have dropped out of high school than his/her counterpart who comes from the highest quartile” (Tucci, 2009). Not only does this strengthen the claim that there is a prevalent achievement gap, but also allows for a more feasible solution rather than completely changing the country’s school curriculum or something of the like. This illustrates the reality that setting up a quality education base for children in lower socio-economic standards (SES) opens up new pathways that not only are beneficial for social mobility and the lives of those affected, but also sets up essentially a chain reaction that leads to benefits for society as a whole. The existence of such aforementioned studies and policies such as No Child Left Behind – an attempt to improve educational standards and performance - affirm that it is evident that there is a problem in the distribution of quality education specifically in low SES areas; ignoring the problem only exacerbates the problem and ignores the benefits that can be attained from widespread quality education.

Aside from possible solutions based off broad system, advancements in the understanding of neuroscience have shown that education during childhood – the critical period – is crucial for essentially establishing a malleable and able mind for further academic and professional achievement, and thus should be considered when attempting to address this issue (Edin, Macoveanu, Olesen, Tegné´r, and Klingberg 2007). Understanding the underlying neuroscience basis of education and learning can provide a guideline for setting curriculums and alternative methods of teaching that can provide pursuing education as a more viable and attainable life path for disadvantaged children, and in turn benefit society.

**SES Environment as an Inhibitor of Intellectual Fulfillment**

Although there has been a good amount of studies that suggest heritability as the main factor in determining intelligence levels, collectively Turkheimer, Waldron, D’Onofrio, and Gottesman (2003) and Gray and Thompson (2004) have noticed a trend that attributes heritability as the main determinant for IQ level is not true among children and families with low SES statuses. Accordingly, “nature is more significant than nurture when socioeconomic status is high, while the reverse is true when socioeconomic status is low” (Gray and Thompson 2004). This is likely due to fact that “developmental forces at work in poor environments are qualitatively different from those at work in adequate ones” (Turkheimer et al., 2003). This relates to the observation that mice that were raised in a “stimulating environment have significantly more white matter” according to Turkheimer et al. (2003), which is physical evidence of higher intelligence as it is a structure related to cognitive function. This directly supports and relates to the idea there is a significant weight on the importance of environment when discussing the degree of heritability of intelligence. The fact that many studies have come to this conclusion is striking considering the difference between achievement differences among different SES groups and correlates the statistical finding that low quality education results in a diversion away from academia, especially since intelligence and academic performance essentially go hand-in-hand. This general idea is a conviction to society to find ways to improve education for children in lower SES conditions to provide them with an equal opportunity.

**The Critical Period of Brain Development**

Childhood is viewed as a crucial period by neuroscientists as a time of brain maturation that requires quality education and cognitive stimulation for best development (Garlick 2002). Thus when considering how to close the achievement gap it is crucial to consider the quality of education in early elementary grade levels and how those settings can in turn affect the future of the children – specifically in low SES areas where there is the evident problem of the achievement gap which is characterized by a discrepancy in academic performance among such factors as race and economic standing. While it is important to consider that “if the appropriate connections are to be developed for particular intellectual ability, a person would be required to be presented with the appropriate stimulation during childhood, while intellectual abilities are still observed to be able to change” (Garlick 2002). That is to say, that if children are not exposed to and properly taught academic subjects such as math and reading, then they will perform more poorly and be significantly disadvantaged at higher grade levels and when learning new material as a result of the weak neural connections established during adolescence.

By essentially neglecting the importance of the critical period, children who do not receive quality education at an early age are at a disadvantage in developing their full cognitive potential. This handicap can act as a root cause for impeded success in such children’s lives. This relates to the finding that students who view themselves as less capable are much more likely to drop out of high school (Guay, Vallerand, and Fortier 1997), as the shoddy education that many children receive is precursor to dropping out as it prevents them from fully developing their intellectual capabilities which then directly affects their self perception. Relating back to correlation between
dropping out and crime, the low education quality can also be viewed as a situation that places children of low SES conditions in a position to more likely to be a strain on society whether in regards to economics or crime - as it puts them in a situation where they are more likely to drop out. Essentially, the poor education quality given to children in low SES conditions puts them at a major disadvantage in regards to pursuing education as the low quality of education provided to them essentially inhibits their ability. This is a precursor to low self-perception and ultimately dropping out. Thus low quality education can be related to a vicious cycle that perpetuates a persistent problem that is both straining on society and detrimental to the lives of those it affects.

Indicators of Intelligence: Structural Integrity and Neural Connections

To best understand how to address the problem of the achievement gap by utilizing an understanding of neuroscience, the relation between the anatomy or physical structure of the brain and the relation to differences in levels of intelligence must be considered in order to assess how different methods directly affect the structure of the brain. Two main properties have been identified in regards to the anatomy of intelligence to be of significant importance: the structural integrity as well as the efficiency of neural connections. The physical structure of the brain - size, volume, and structural integrity – has been shown to correlate with levels of intelligence but is not the sole, or a universal predictor of all intelligence (Singer 2009). However, there is a high enough correlation between brain structure and intelligence that a change in the structure as a result of some cognitive task can safely be associated with some positive change in intelligence or cognitive ability. Whereas neural efficiency relates to intelligence in the sense that more neural connections allow for easier understanding of a topic - as the subject has essentially been more imprinted in the brain – which enables higher intelligence (Singer 2009). In addition, those established connections allow for broader understandings of a subject, as those connections must be strongly established to best grasp the topic. Furthermore, these established connections provide the basis for continued learning – such as for a student to continue to learn mathematical concepts.

There are significant correlations between volume of some sub-regions of the brain and levels of intelligence. Specifically the strongest evidence was found “between intracranial volume and Verbal IQ, performance IQ, and full scale IQ” (Andreasen et al. 1993). Despite these findings Andreasen et al. (1993) concluded:

[That] the modest correlations of the relationships must be emphasized. Significant correlations ranged from 0.26 to 0.56, indicating that between 12% and 31% of the brain variance can be accounted for by the size of the brain or its subregions... we must conclude that although size may be among factors related to human intelligence, many other factors must also be important....The answer resides in aspects of brain structure that reflect ‘quality’ rather than ‘quantity’ of brain tissue (p. 133).

This idea that brain volume is a significant indication of intelligence level, but not a sole explanation or necessarily a reliable one has also been concluded by many other studies and researchers. Especially considering that “total brain volume accounts for about 16% of the variance in general intelligence scores” (Haier et al. 2004), which is in line with Andreasen et al.’s (1993) findings. Furthermore, there are very similar conclusions that have “linked intelligence to overall brain size”; but that the exact reason for the correlation is unclear proposing that it could possibly be because “they have more nerve cells, more connections between cells, or more of the fibers that carry neural signals” (Singer 2009). Singer (2009) constantly acknowledges that anatomical measures of intelligence are very complex and that there is no one predictor or indicator of intelligence, in line with Andreasen et al.’s (1993) conclusion of multiple viable yet not ultimate indicators of intelligence and the multiple different studies attributing different factors to intelligence. Thus, when identifying certain methods of intellectual gain, a concept that results in a physical change of the brain can receive more authority and importance than a concept that solely shows statistical improvements. It is important to not consider this ultimate indicator of how to scientifically measure changes in intelligence, as intelligence is not determined by a single factor and is not composed of one single process. Nonetheless, integrating methods of cognitive training that have been shown to cause structural changes in the brain into school curricula can serve as a viable part of the approach for improving education.

It is no surprise that the intelligence – a metaphysical result of the arguably the most complex human organ – is characterized by multiple qualities. As Singer (2009) and Andreasen (1993) both assert, the efficiency of neuronal connections in our brain may serve as a main process behind the varying levels of intelligence. As aforementioned, this deals with the quality of the brain rather than the quantity per se. As Singer (2009) notes, it is the efficiency of the connections rather than the speed as many have presumed – this includes more direct connections as Singer references Martijn van de Heuvel’s, of the University Medical Center Utrecht, work by providing the analogy “just as a direct flight from Paris to Chicago would be considered more efficient than one with a layover in London, a direct link between two parts of the brain would be more efficient than an indirect route”. van de Heuvel, Stam, Kahn, and Pol (2009) provided evidence for this theory noting that there is an “existence of a strong association between the level of global communication efficiency of the functional brain network and intellectual performance”. In essence van de Heuvel et al. (2009) found that “efficiently functionally connected brains” are highly correlated with high intelligence measures. Rypma et al. (2006) further strengthens this finding through their conclusion that “the extent and direction of influences between brain regions underlie cognitive efficiency and individual differences in performance”. The basis of neural efficiency lies in using the connections that are established, rather than priming them or
increasing the speed of the connection. Thus in order to improve the neural efficiency, more quality connections must be established.

The idea of establishing more routes to an endpoint is complemented by the notion of the saturation of a concept. When considering how to improve education in an early elementary setting in low SES conditions, the concepts taught must assuredly be understood – i.e. mathematics, reading - in an in depth fashion in order to fully establish and create those connections. As well as to continually build off that base for further quality learning and to later fathom the more complicated subjects. That is to say the students must have a firm grasp on a concept before they can progress. In concept, this idea would promote certain teaching styles or strict standardized tests for grade progressions. However, in practice strict delegations may have a negative impact on school systems and cannot be guaranteed to be followed.

A solution to the challenge is exemplified by the finding that students who were the most engaged in learning and exhibited the most understanding of a subject saw real life significance in the task that they were learning, according to Purcell and Dahl (1991). Specifically the students who learned the most “indicated during the pretest administration that print said something meaningful and that it was used for transactions in the world such as at the bank and on games to tell you what to do. The less successful children, the Curriculum Dependent Learners, could only indicate that print consisted on letters or numbers which existed in school to be learned” (Purcell and Dahl, 1991). This is also important to consider when teaching, so that the children see a significance in the task they are being taught in order for them to become more engaged and actually learn and understand the subject. This can apply to teaching in general, however, in light of the importance of establishing strong neural connections at a young age, this method is a viable one to ensure that.

This concept of neuroscience – efficiency as an indication of intelligence – relates directly to both the previously mentioned statistical finding that environment plays a stronger role in low SES condition and to the concept in neuroscience of the critical period. The concept of the critical period illustrates that childhood is crucial for establishing neural connections of a concept in order to be able to fathom that concept later on. As previously mentioned, neural efficiency – which is based on neural connections – is directly related to intelligence. By essentially inhibiting the connections made, low quality education inhibits the fulfillment of intellectual ability. This concept provides a view from neuroscience that complements the statistical finding that that the degree of “nurture vs nature” of intelligence favors the nurture side in low SES conditions (Turkheimer, Haley, Waldron, D’Onofrio, and Gottesman 2003). This serves as further evidence for the need of improvements in education as many students are prevented from fulfilling their intellectual potential – and consequently their academic potential - as a result of the low quality of education they receive.

Working Memory: A Component of Intelligence

Since intelligence utilizes certain cognitive abilities, it would make sense that a sort of cognitive training can be utilized in order to improve ability. If cognitive training is utilized in the classroom it can bring about positive changes in academic achievement. One of the main cognitive functions theorized to correlate with levels of intelligence and tasks that measure intelligence is Working Memory (WM) (Kylatta and Lehto 2008). If this specific function does indeed mediate intelligence levels, then training WM can in fact partially compensate for lack of quality curriculums – among other issues. And ultimately provide a stronger base for learning and result in improved abilities, which would consequently induce more motivation to continue with education.

Working Memory encompasses the ability to maintain and manipulate information –such as remembering a sequence of numbers –and is associated with complex reasoning (Edin, Macoveanu, Olesen, Tegne r, and Klingberg 2007). Based off this, it makes sense that working memory and intelligence would be connected since mathematical performance is a major factor of determining general intelligence – g – and working memory appears as a process used while solving mathematical problems (Kylatta and Lehto 2008). Furthermore, based off their studies and statistical analyses, Kylatta and Lehto (2008) conclude that “both passive visuo-spatial storing (measured with short- term storage tasks), active visuo-spatial processing (mental rotation) and fluid intelligence are crucial in maths skills”. Kylatta and Lehto (2008) further assert that working memory is indeed an underlying function utilized in mathematical tasks claiming specifically that:

Both passive visuospatial (simultaneous) storage capacity and non-verbal intelligence are uniquely related to general maths performance…. Passive simultaneous visuospatial-WM and fluid intelligence (that probably included active VSWM ability) predicted general maths performance and success in mental arithmetic….Geometry was best accounted for by fluid intelligence and active VSWM. Intuitively, the role of mental rotation can be understood as follows: both the rotation task and geometry require the ability to process abstract visual stimuli. Passive sequential VSWM (Corsi Blocks) and fluid intelligence explained word problems (p. 89).

However, working memory in and of itself is not what accounts for varying levels of intelligence and performance on mathematical tasks, but rather as a mediator between intelligence and cognitive tasks, specifically mathematical performance as Kylatta and Lehto (2008) points out to clarify the connection. Working memory allows for more “mental workspace” as Grabner et al. (2006) phrase it or a bigger “mental blackboard”, as Kylatta et al. (2008) phrases it, that can be manipulated in the completion of certain cognitive tasks i.e. reading or mathematics, which further suggests that more intelligent individuals have
larger working memory capacity as intelligence is measured by cognitive tasks that working memory assists in. Acknowledging the fact that intelligence is not predicted by one single factor, Mogle, Lovett, Stawski, and Sliwinski (2004) compared the correlation of other cognitive functions, in addition to working memory, to intelligence and found, in accordance with Kylattta and Lehto (2008) and many others, that working memory is indeed strongly correlated with levels of intelligence, further emphasizing the correlation. Thus it is evident that manipulating this knowledge of the relation between WM and cognitive ability will prove useful when applying an understanding of the neuroscience of intelligence to alleviate the achievement gap.

Cognitive Training Improves Intelligence Measures

Knowledge of what underlies intelligence can prove useful for improving education, but the extent and even existence of its variability must first be considered to properly apply it. Specifically, if intelligence is variable what method and to what extent can working memory be improved in order to expect improvements in ability and performance. Since it evident that WM mediates intelligence, evidence that shows that WM is malleable is necessary to apply this type of training to educational settings.

As discussed previously, the physical structure of the brain can give insight into intellectual capabilities, accordingly changes or lack thereof of as a result of WM training can elucidate if and what those training tasks work. The theory that cognitive tasks can alter the brain structure appears to be the case as “early, intensive, and prolonged” cognitive task training does actually cause structural changes in the brain, indicative of a positive change in physical indications of intellectual capability (Gottfried Schlaug et al. 2002). To account for this, Klingsberg (2010) noted that the aforementioned cognitive function improvement as a result of training is established through “neuronal changes from the intracellular level to functional organization of the cortex” which in concurrence with Schlaug et al.’s (2002) identification of structural changes as a result of cognitive training. Additionally, Takeuchi et al. (2010) illustrated their findings that training in fact increased the density of white matter and elucidates that his findings are indeed proportional to the amount of training rather than an effect of normal development. Interestingly enough, Singer (2009) noted that rodents raised in a “stimulating environment” in fact have a larger amount of white matter, which is in direct concordance with the finding that cognitive training affects brain structure – specifically white matter. Singer (2009) also notes the idea that smart individuals are more intelligent because they gravitate towards “situations that further enhance their intellectual ability” which further strengthens the finding that constant exposure to cognitive tasks affects both ability and structure. Thus, since working memory training has shown that it can induce changes in the brain that relate directly to changes and factors indicative of intelligence – as discussed previously – it can be safely presumed by this qualitative evidence that working memory training does indeed have significant benefits.

Since it is established that working memory training can improve capability through physical evidence, the statistical evidence and factors that affect the performance improvement must also be considered. Holmes et al. (2009) found that the group of children that participated in an adaptive training session – the level of difficulty changed with their ability – was the group that had the most significant and lasting improvements in performance. Jaeggi, Buschkeul, Jonides, and Shah (2011) assert that the amount of transfer gain – increase in general intelligence as a result of WM training - is mediated by the WM improvement of each participant, this is similar to the finding of Holmes et al. (2006) that the adaptive group received the most significant gains. This presents both a guideline and an obstacle for implementing working memory training. Students are going to have to be grouped according to their ability and be constantly tested so that training is incremental and consistent with the level of their ability so that they receive the most benefits according to the conclusion reached by Holmes et al. (2006). However, this also may be harder to implement without technology as the amount of teachers available may limit the amount of groups that students would be grouped in if the training were to be administered by person.

Jaeggi et al. (2011) also focused on the transfer effect of WM training on fluid intelligence and found that there is a boundary effect in which a certain thresh hold of improvement must be met for transfer effects to be prevalent. Consequently, when using cognitive training, specifically for working memory, it is crucial to recognize that training must be consistent and intensive, rather than seldom and viewed as a solid improvement at each session, in order to fully utilize the benefits. This is again very similar to Holmes et al.’s (2006) finding that lasting benefits are attributed to the group that was allowed to make gains by levels relative to their ability, in the sense that there are certain requirements for training to best be benefited from. Jaeggi et al. (2011) assert that it is established that cognitive training does indeed work, and that research “should not investigate whether brain training works, but rather, it should continue to determine factors that moderate transfer and investigate how these factors can be manipulated to make training most effective” which demonstrates the soundness of its benefits. Since it is evident that cognitive training, specifically of working memory, works it is a reliable method to suggest for alternative methods of teaching that could result in improved academic performance with the ultimate goal of being a part of the solution to alleviate the achievement gap. Klingsberg (2010) also found that “training can improve performance in a wide range of functions” which further presents this method as reliable as it would have broad benefits rather than being concentrated in one specific task.

The most effective and efficient way to administer WM training is through computer programs such as the program designed by the renowned neuroscientist Torkel Klingberg of CogMed and his colleagues. Along the lines of both Holmes et al. (2009) and Jaeggi et al. (2011), training should last for about 20-35 minutes and be administered three to four times a week.
However, it is crucial that the programs adapt to the level of the children for optimal improvement – as concluded by both Holmes et al. (2009) and Klingberg (2010). This is a major advantage of using a computer program, in addition to the fact that it would include a much broader and more extensive field of training tasks. As clearly elucidated by Holmes et al. (2009), the working memory tasks should include:

Temporary storage and manipulation of sequential visuo-spatial or verbal information, or both… temporary storage of sequences of spoken verbal items, such as letters… the immediate serial recall of visuo-spatial information… the immediate recall of a sequence of digits in backward order… the processing and immediate serial recall of visuo-spatial information that [is] either moving around the screen during presentation and recall or mov[ing] spatial location between presentation and recall.

Conclusion
The U.S. would benefit from elevated social conditions that accompany reduced crime rates, not to mention the significant quality of life improvements for the individuals that would benefit from change in education. Cognitive training and an understanding of neuroscience are methods that may not fully solve the problem of the achievement gap and its aforementioned implications, but they still hold authority as viable options that can be adapted by teachers and schools, specifically those in lower SES conditions, in order to improve performance. Ultimately, the information presented here can be considered as a call to action to improve arguably one of the most important aspects of society and as a starting point of the solution that assures broad, accessible quality education.

REFERENCES