Reports by the World Health Organisation (WHO) reveal that more than 40% of the world’s undernourished children live in India. A similar percentage of Indian children under five years are underweight and a higher percentage is stunted due to chronic undernutrition. More than 50% of school children are suffering from nutritional anaemia.

Now, what about quality of learning? Here, learning definitely does not mean marks and grades achieved by a child in any specific examination. It is about holistic performance of a person in terms of intellectual abilities (usually indicated by, but not limited to, academic performance), personality traits, socio-emotional aspects, and ability to know, do and think.

Several Government, Non-government and independent organisations have raised questions about the miserably low and further falling learning levels among school children. Performance of 15-year-old Indian students was the second worst among 73 countries in the largest Programme of International Assessment, PISA-2009 (methodology of PISA was caught in controversy, but findings are similar to many Indian studies).

Could there be a relationship between the two kinds of reports discussed above? Does nutrition during the early years of a child influence his/her academic performance in later years? Does a particular nutrient have more impact on learning abilities?

Before answering these questions, let us first understand the interplay of brain structure, learning process and intellectual abilities. Many such studies are based on IQ (Intelligence Quotient) as a measure of intellectual abilities and therefore academic performance, and relate to either neural or biological i.e. genetic basis of intelligence.

Neural Basis of Intelligence

In the last few decades, extensive research has gone into demystifying and validating the interlinkages of intelligence with hereditary factors, and the structure and functioning of brain.

The brain occupies approximately 2% of the total body weight, but consumes 20% of the calorie intake. Brain cells need a continuous supply of oxygen and glucose to produce energy and its function is highly sensitive to the availability of nutrient supplies.

Scientists have found different degrees of correlation between intelligence (in terms of IQ or other scores) and head size, brain volume and ratio of brain weight to body weight. But recent studies suggest that brain size alone isn’t indicative of intelligence. Einstein’s brain, which was preserved, is much smaller than average!

The size, shape and activity levels of the different regions or lobes of the cortex are of special significance for learning. Overall thickness of the cerebral cortex and neural efficiency too impact various aspects of learning.

Nature or Nurture – What shapes the intellectual abilities of an individual? This has always remained a debatable issue among scientists as well as academicians. Non-genetic factors are equally responsible for variation in academic achievement among students as much as genetic. Nutrition is one of the most important non-genetic factors that influences learning, usually measured in terms of academic performance.
Although different parts of the brain are associated with different aspects of learning ranging from hearing, seeing to memorizing and thinking at higher level, most of the neural functions are due to the interaction and collaboration among multiple areas.

On the other hand, Haier and colleagues (2004, 2007) on the basis of imaging studies and review conducted at University of California, suggested that intelligence is not so much related to brain size or brain structure but to how efficiently information travels through the brain. They also proposed a new theory that identified areas in the brain that work together to determine a person’s intelligence.

Many studies suggest the significance of the following neural processes in determining intelligence:

- Formation of neurons, synaptogenesis (formation of synapse at neuron junctions), dendrite differentiation and myelination. These processes are very active before birth and continue at a lower pace until adolescence. There is evidence of these processes in adults too, but rarely. The role of the synapse is critical in information transmission from the axon of one neuron to the dendrites of another. This process is governed and mediated by a variety of neurotransmitter molecules. These neurotransmitters are derivatives of either fatty acids or amino acids. That is why synapse is often referred as chemical synapse. This information flow is of great significance and forms the foundation to understand the process of learning.

Communication between neurons through synapse

- Synthesis and release of neurotransmitters, receptor synthesis, and neurotransmitter reuptake and inactivity mechanisms. These are the molecules and processes responsible for carrying information from one neuron to another. Interference with production or functioning of these molecules leads to changes in metabolism and signal propagation and hampers normal functioning of the brain and associated parts.

**What Matters – Grey or White**

The human brain consists of about 60% white matter and 40% grey matter, but about 94% of the oxygen requirement of the brain is consumed by the grey matter. White matter is the infrastructure of the brain and consists of axons and protective layer of fat, myelin. Grey matter plays a key role in memory, attention, perception, thinking, language and consciousness.

Both grey and white matters have been reported to be related to IQ, but correlation is greater for grey matter. Stronger correlation for grey matter implies stronger correlation with the number of neurons. While grey matter amounts are vital for intelligence, researchers surprisingly found a link of only 6% of grey matter to intelligence, which also indicates that grey matter of only specific brain regions may be related to intelligence.

In 2014, a study conducted by researchers at King’s College, London shows that the thickness of grey matter in the brain may be linked to intelligence and may also explain why some people have learning difficulties.

**Critical Stage of Neural Development**

As reported in *Science Daily* magazine (2006), poor nutrition early in life can impair neural development, leading to lower IQ in humans and even flawed song learning in birds.

The brain grows rapidly just before and for about two years after birth. So, the first two years of a child’s life are considered as very important. The rapidly developing brain is more vulnerable to nutrient inadequacy and insufficiency. Researchers argue that the timing of malnutrition is an important factor in determining the magnitude of the problem. Missing a particular nutrient at a time when a part of the brain is growing and needs that particular nutrient may result in specific problems.

The brain develops very fast in the prenatal period and till the age of two years. In infants, neuronal connections are undifferentiated and become more

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*A feature article on the functionality and development of the brain.*
Nutrients in the diet have a significant role in shaping the neural structure of the brain and determining the learning abilities and intellectual potential of a person. This is because the critical stage (or age) for neural development and cognitive development is almost the same. Nutrient deficiency during this age may lead to irreversible changes in the structure of the brain.

Complex during adolescence. This is also the time-frame for development of general factor of intelligence that is measured by intelligent tests.

The capacity of the brain to adapt to environmental stimuli reduces over time. It follows that there is a critical period for intellectual development as well. Evolutionary studies also suggest that in more intelligent individuals synaptogenesis is better i.e. neurons are more efficient in formation of synapses.

So, to develop certain intellectual abilities, a person needs to be provided with the appropriate environmental stimuli during childhood, before the critical period for adapting their neuronal connections ends.

Nutrition and Learning

Researchers suggest that poor nutrition during neonatal, infancy and below six years of age can have lifelong effects on cognitive development and compromise academic performance. Cognitive development includes human perception, thinking and learning.

In order to learn and perform well at school the student must be active, attentive, curious and explorative. How can undernourished children meet these requirements? Secondly, under- or malnourished children are more prone to diseases and sickness resulting in absenteeism from classrooms, therefore lag behind in classroom performances. Unhealthy children are more likely to become unhealthy and uneducated adults.

The possibility of a strong connection between nutrition and learning is gaining significance. Nutritionists, food and agricultural scientists, social scientists, behavioural psychologists, behavioural geneticists, neurologists, educationists as well as researchers are trying to understand the interactions between specific nutrients and harvest this understanding to improve academic outcomes of children.

Scientists are trying to establish a relationship between the numbers of brain cells and intelligence so that intelligence might be articulated in terms of biochemical processes like metabolic pathways.

Which Nutrients have Greater Impact?

Certain nutrients have greater effects on brain development than others. These include glucose, certain amino acids, certain essential fatty acids, iron, zinc, copper, iodine, selenium, vitamin A, choline, and folate. Earlier studies had suggested that deficiencies in iron and iodine are linked to impaired cognitive development in young children. There is emerging evidence that deficiencies in zinc, folate, vitamin B12, some essential fatty acids and amino acids also compromise cognitive development in children.

Scientists recommend a wide range of foods as nutrient sources, so that they support brain function and neurotransmitter activity. It has been found that children who had inadequate fruit and vegetable intake also showed poor school performance as compared to those students who had an adequate intake of fruits and vegetables.

Protein and Amino Acids: A few amino acids like aspartic acid, choline, glutamic acid, phenylalanine, tryptophan and tyrosine in blood produce and release neurotransmitters like acetyl choline, serotonin, dopamine, etc. Neurotransmitters are chemicals produced inside the neuron body that carry information from one neuron to the other through synapse. Synthesis and release of neurotransmitters is also mediated by the number of enzymes, which are structural proteins. Tryptophan in particular is an essential amino acid and its deficiency is common in cereal-based diets. Dietary sources rich in these amino acids are eggs, meat, skim milk and milk products, bananas, soybeans, almonds and grains.

Fat and Fatty Acids: Some fats are essential for proper functioning of the brain. Fifty percent of the brain mass is made up of fatty acids and over 70 percent of these are long-chain polyunsaturated fatty acids. These fatty acids are required for synapse formation, membrane function, and potentially, myelination of neurons.

Researchers have shown importance of omega-3 and omega-6 fatty acids for the production, maintenance and function of brain cells. There are three forms of omega-3 fats associated with omega-3 metabolic pathway: Docosahexaenoic acid (DHA), Eicosapentaenoic acid (EPA), and Alpha-linolenic acid (ALA).

Synapses (gap between neurons) are rich in docosahexaenoic acid (DHA), a common form of omega-3 fatty acid and play a significant role in signal transmission along neurons. Omega-DHA constitute 30% of the brain mass. Omega-6 fatty acids are also important for the release of neurotransmitters and also influence the ability of neurons to use glucose.

However, omega-3 is a group of essential fatty acids that cannot be synthesised by the body in adequate quantities. Therefore, they need to be supplied through diet. Unfortunately, it is found in very few diet sources like fish oil.

Studies indicate that deficiency in omega-3 fatty acids can lead to increased risk of attention-deficit disorder and dyslexia. Children who had a sufficient
Iron: The brain requires a continuous supply of oxygen that is provided by haemoglobin present in the blood. Iron is an integral constituent of the haemoglobin molecule. Deficiency in iron is directly related to poor glucose metabolism leading to slower movement of impulses, reducing the activity of brain cells leading to poor cognitive function.

Iron deficiency also alters myelination and monoamine neurotransmitter synthesis. Iron deficiency during infancy may cause permanent damage to the child’s brain, while deficiency during the first two years of a child may result in delayed psychomotor development. However, too much iron can also cause problems.

A study by researchers at King’s College, London, found a significant link between low haemoglobin levels and poor mental performance; and reported that teenage girls who suffer from iron deficiency may also have a low IQ. Among students, iron deficiency may lead to increased fatigue, shortened attention span, less work capacity, increased sensitivity to infection and low intellectual performance. Usually, anaemic children tend to do poorly on vocabulary, reading and other academic tests.

Iodine: Iodine deficiency during the early years has been found to be related with reduced intellectual abilities and academic achievement in school-age children. Kids under the age of eight need about 90 microgram per day, while infants up to a year old require between 110 and 130 microgram. Even mild deficiency can cause a significant loss of learning ability, as well as other disorders associated with goitre. The good part is that it is easily preventable (UNICEF, 2008).

Zinc: Zinc is a micronutrient that is present in the brain and influences its structure and function. The grey matter in the hippocampus is rich in zinc and role of hippocampus in memory and learning has been established in a number of studies. Research trials further suggest that the beneficial impact of zinc supplementation may have an impact on attention and reasoning, which are important aspects of learning.

Vitamins: Vitamin A deficiency generally is very common along with malnutrition. It often leads to Xerophthalmia – ‘disease of darkness’ – among children younger than five years old due to lesions in the cornea. It has not yet been estimated how many children don’t perform well in school due to visual problems caused by vitamin A deficiency.

Vitamin B has been found to be closely associated with neural activities and thus is supposed to be involved in cognitive functions. Deficiency of vitamin B1 (Thiamine) damages the myelin sheath and axons of the motor and sensory nerves. Vitamin B6 (Pyrodoxine) and vitamin B12 (Cobalamin) have significant role in production of neurotransmitters and myelin formation, respectively. Deficiency of vitamin B12 causes degeneration of white matter in the brain and nerves.

Vitamin C has been found to play a role in the formation of serotonin and dopamine, whereas vitamin E plays a protective role for fatty acids. B12 and folic acid are involved in synthesis of haemoglobin that has strong relation with performance.

Studies into how nutrition affects the brain and behaviour are relatively new. Scientists have just begun to analyse how changes in particular nutrients change the neurology of the brain and how these neural changes affect intelligence, mood, and the way people respond to a particular situation.

Besides, different people respond to different diets in different ways. There is still a long way to go before scientists are able to demystify the science of nutrition and intelligence, but there is no denying that what we eat has a great impact on how we think and how we learn.