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Science Education in the Context of Neuroscience: A New Philosophical Paradigm?

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Abstract

Proponents of science education have been debating for years on the issue of student-centred versus teacher-centred dichotomy. From the debate, the knowledge body of the field has expanded, and it informs science educators on the best ways to teach science to novice learners. Discoveries in neuroscience on how the human brain works have provided some exciting information on the mechanism of human learning at the physiological level. Thus, this paper attempts to formulate the notion of – neuroeducation as a promising contemporary philosophy to guide science education to move forward in the 21^{st} century setting.

Keywords: science education; neuroeducation; philosophy; teacher-centred; student-centred

1. Introduction

Upon his return from a two-week vacation, often described by his colleagues as a careless scientist, Alexander Fleming discovered that mold had developed on a staphylococcus culture plate. Being a curious man of science, Fleming examined the contaminated plate and he noticed that the culture suppressed the growth of nearby staphylococci. Accidental as it was, the occurrence that took place in Fleming's laboratory in 1928 marked the advent of penicillin (Fleming, 1944; Hilding, 1998; Brown & Wright, 2016). Since the first patient who was successfully treated for streptococcal septicaemia in 1942, penicillin has been the most widely used antibiotic to date and it has saved millions of lives across the globe. Ergo, the serendipitous event has paved the way for penicillin to become one of science's remarkable inventions that enables our modern world. Science, in general, has always been synonymous with advancement and prosperity.

Conant (1948) in his writing entitled "The Role of Science in Our Unique Society" extrapolates that science may possess the quality to play a pivotal determining role in the outcome of national affairs. He asserts that to ensure the continuation of the welfare of its economy and national sovereignty, every industrialised nation would be dependent on the advancement of applied science. Mavankar (1956) in his article adds that science as a progressive field is not merely elevating the living standard of people but alters the way people think about relating with one another as well. The best example of Mavankar's prediction can be seen in how the fields of business and marketing nowadays are actively seeking better ways to engage with customers through web 2.0 and social media (Duffett, 2015; Alalwan et al., 2017). Therefore, it is evident that research and breakthroughs in science serve as the impetus for a positive trajectory of a nation's development. Of course, the flourishment of scientific knowledge goes hand in hand with a good influx of scientific literate individuals into the field of science and to do this, machinery in science education is ought to be capable of equipping students with stellar scientific skills.

2. Science Education: A Dynamic Landscape Informed by Philosophy

The landscape of science education will morph by the developments in science. Take the story of how Sputnik triggered the Americans to initiate a restructuring on their science education framework. The Pre-Sputnik era saw science education in the United States of America (the USA) was deliberately made exclusive for the elites (Cha, 2015). To exacerbate the limping state of the American science education at the time, American scientists and proponents of science were facing a challenge to convince the public of the utility of science and the importance of scientific literacy of society. This was because the humanities were deeply ingrained as the subjects that were thought, if compared to science, to lead to the noblest and worthy educational outcomes (DeBoer, 2000). The moment Sputnik 1 beeped its radio signal from space on the 4^{th} of October 1957, it galvanised the fear and anxiety about the perceived technological gap between the USA and their Cold War rival, the Soviet Union. Consequently, tremendous changes took place on the American science education landscape that involved the allocation of more funds to improve science education and the shifting of science teaching and learning philosophies (Cha, 2015).

From the story of how the first satellite launched into space provoked a science education system that was deemed to be the best at the time, it is learned that philosophical standpoint influences the implementation of science education. Post-Sputnik, one of the biggest attacks was on Dewey's philosophy of education that was massively influential amongst American schools around the 1930s and 1940s (Westbrook, 1993). Americans found fault in the upheld philosophical standpoint that championed life-changing training and behavioural conditioning education but alas, missed the mark at developing intellectual excellence (Herold, 1974). Indeed, philosophy is an important aspect of science education because of its connection with critical thinking. It is known that logic is paramount to philosophy. Logic as expounded by Hegel (2014) is the science of thinking in general and it is understood that thinking comprises the sole form of cognition that logic abstracts from. Ergo, logic as an integral part of philosophy is the science that enables people to analyse the degree to which a conclusion follows from premises and to identify fallacies. Whether it was for the American science teachers in the 1950s or all teachers around the world in the present day, it remains true that philosophy informs the way they discuss values, set priorities, and formulate educational goals.

The progress in science opens the gate to the widespread globalisation whereby the exchange of and access to information that was previously reserved for a few, can now be available to everyone. Globalisation raises possibilities for growth and development in the science classroom. The advent of new technologies offers a vast amount of information and resources for teachers and students. Let's take Google as an example, it has revolutionised the way science students research for a project and the internet provides them with the opportunity to be seamlessly connected with other students, teachers, and science professionals from every corner of the world. In the 21st century, science teaching and learning surely begs for new philosophical viewpoints to match the emergence of new educational needs and challenges in science. Thus, the purpose of this paper is exactly this – to introduce neuroeducation as a promising philosophy that presents human learning to be more than just an abstract concept, it constitutes the physiological impacts of learning. Furthermore, to make the neuroeducation philosophy argument appear more appealing, a strategy is adopted by which a comparison is drawn against two long-standing philosophies in science education, i.e., teacher-centred and student-centred approaches.

3. Teacher-Centred and Student-Centred Pedagogies: Long-Standing Philosophies of Science Education

Research on the implementation of student-centred pedagogy in science education is often reported with a juxtaposition to its teacher-centred counterpart. In most of the reports, the latter is promulgated as the inferior version of the teaching and learning paradigm for science in modern classrooms. The notion is due to the perceived nature of teacher-centred pedagogy which tends to produce passive learners in science. Two philosophical underpinnings serve as the foundation for the pedagogical approach – essentialism and perennialism (Ellis, 2014).

Educational essentialism is a school of thought that stresses the adherent to the belief that children are ought to be taught the traditional basic subjects thoroughly, i.e., enacting a back-to-basics approach. Essentialists in education favour the idea of knowledge is transmitted by teachers to students via a core curriculum (Ambrose, 2005). On the other hand, perennialism is a philosophical viewpoint that conjectures in student acquisition of knowledge that is timeless and enduring across civilisations and cultures. Like essentialism, perennialism emphasizes the role of teachers as masters of knowledge and hence transmit them to students. Furthermore, the classroom aims to be a closely organised, and well-disciplined environment. In science education, the philosophy serves as the basis for the notion that education should epitomise a prepared effort to make scientific knowledge available to students and to guide their thought processes toward the understanding and appreciation of the great works by history's finest scientists that transcend time and never become outdated (Gutek, 1997). Therefore, based on these teacher-centred philosophies, the science teacher assumes a dominant figure who establishes complete control over the learning process, i.e., determines learning objectives, structures learning tasks and decides the time and method for task completion. The students, on the other hand, act as passive recipients of science information and they have very little say in how science lessons would be best presented for them (Lancaster, 2017).

When science and education have stepped into the 21st-century era, skills such as competency in collaborative working, ability to communicate effectively and possessing the capacity to solve real-world problems become the educational outcomes that are highly sought. The United Nations Educational, Scientific and Cultural Organization (UNESCO) posits that 21st-century skills can be adequately acquired by students through the administration of student-centred project-based learning (Luna Scott, 2015). Contrary to teacher-centredness that prioritises examination-oriented goals – students' learning motivation is driven by competing for better grades and rewards, student-centred instructions capitalise on problem-solving approaches through working cooperatively (Lynch, 2010; Lancaster, 2017). Cooperative learning provides opportunities for students to achieve goals more efficiently in the science classroom and thus learning ownership is shared by groups of students (the teacher assumes a facilitating role rather than dictating). Apart from acquiring academic excellence, science students who are adept at cooperating with their peers develop critical thinking skills and they will be more sensitive towards different perspectives in shaping them into more confident scientific literate individuals (Marzano et al., 2001).

Student-centred pedagogical strategy is closely related to the constructivism philosophy, and it can be seen in the role of teachers as a learning facilitator/mediator that fits with the Zone of Proximal Development (ZPD) tenet as proposed by Vygotsky constructivist theory. As expounded by Vygotsky (1987) ZPD is upon the psychological functions which have yet to mature but are in the process of maturing. The concept of ZPD as it functions within Vygotsky's theory of constructivism supports a depiction of academic advancement based on permanence. Learning can propel cognitive growth. Thus, in science, the role of the teacher is to help the students to mature their scientific knowledge through social means.

4. Science Education in the Context of Neuroscience: A Promising Philosophical Paradigm?

Scientific discoveries around brain research have attracted the attention of other fields, especially education. Educators who are keen to explore the field of neuroscience – a multidisciplinary science that studies the functional architecture of the brain and nervous system (Cubelli, 2009), believe that it can provide valuable insights into children's learning and give useful pointers for improving teaching practice. The field has experienced steady growth over the last three decades and it has forged links with other fields that share the passion for human development. Neuroscientists utilise brain imaging tools in the attempts to learn about the neural mechanisms of brain activities such as (Otte & Halsband, 2006):

- *Electroencephalography (EEG)* – A typical non-invasive electrophysiological method to record electrical activities of the brain on a millisecond level. The electrodes are placed along the scalp and the resulting traces are called electroencephalograms that represent an electrical signal from many neurons. This method yields high temporal resolution.

- *Positron Emission Tomography (PET)* – A method that utilises a short-lived radioactive substance called a tracer to check for brain activities. The tracer is absorbed into the bloodstream and attaches itself to glucose which is the main fuel of the brain. Hence, when an active area of the brain consumes the glucose, it will take in the radioactive tracer as well. The tracer undergoes a radioactive decay to emit positron, which can be detected by the PET. A brain PET scan allows neuroscientists a view of not only the structure of the brain but how it's functioning as well.

- *Functional Magnetic Resonance Imaging (fMRI)* – This method is like EEG which is a non-invasive neuroimaging technique. But unlike PET, it does not include the administration of a radioactive tracer. The machine rather detects the flow of oxygenated blood to the area that has any neural activities. When a brain area is more active it consumes more oxygen and to meet this increased demand blood flow increases to the active area. Over the last decades, fMRI has helped shape brain research in the investigation of how memories are formed, language, pain, emotion, and learning. This is due to its excellent spatial and temporal resolution in producing activation maps showing which parts of the brain are involved in a particular mental process.

Multiple terms exist to denote the union of neuroscience with cognitive science, psychology, and education in the quest to investigate the learning brain. Geake (2009) and Campbell (2011) refers to the union as "educational neuroscience" whereas Howard-Jones (2011) and Ansari et al. (2012) are more inclined to use the label "neuroeducation". Some scholars like Schwartz and Gerlach (2011) believe that the term "Mind, Brain and Education (MBE)" is a more suitable umbrella term for the union of neuroscience with other fields. Although the terms may be used interchangeably, for the convenience of this paper the term "neuroeducation" is used to describe it as an interdisciplinary field that may possess the potential to bring forth useful transformations onto educational practices, especially in the science classroom.

During its inception in the early 1990s, scholars welcomed neuroeducation a new field of inquiry with scepticism. One of the earliest critics of neuroeducation is John Bruer (1997) who wrote in the article "Education and The Brain: A Bridge Too Far" has stated that there is a huge gaping chasm between our comprehension of how experience affects synapses and our understanding of what happens or should happen in the classroom. Despite the vast number of breakthroughs in neuroscience, he was sceptical towards the fact that empirical evidence and breakthroughs can give much guidance for education policy and classroom practices. The strong resistance however did not stop the Organisation for Economic Cooperation and Development from attempting to bridge neuroscience and education. In 2002, the OECD released a publication entitled "Understanding the Brain: Towards a New Learning Science" of which a compilation of key points generated through the OECD's "Brain and Learning" initiative that had brought international scholars and researchers together in the effort to discuss the issues and potentials of neuroeducation

(Ansari et. al., 2012). In a more recent article, a group of neuroeducation proponents has attempted to highlight the ways we can bridge education and neuroscience. They disagree with Bruer's idea that suggests the linear flow from neuroscience to cognitive psychology and eventually education neuroscience and cognitive psychology work in synergy and concert to improve education (Sigman et al., 2014).

Before the neuroscience era, science education was primarily informed by philosophical intelligence and discoveries in the field of cognitive psychology. Adhering to teacher-centred pedagogy, science teachers justify their teaching styles using the tenets originated from great existentialists (e.g., Fallico (1954), van Morris (1954), and Hilker (1977)); perennialism philosophers (e.g., Hutchins (1969) and Adler (1982)). On one hand, a science teacher who upholds the philosophies of student-centred learning will be influenced by the writing of constructivists like Piaget (1971) and Vygotsky (1987). Now, in the existence of neuroscientific knowledge, science education has become a fertile ground for neuroscientific applications. In a qualitative study that involved thirteen education practitioners who were repeat attendees of a series of "Learning and The Brain" conferences – the conferences provided chances for the practitioners to get in touch with neuroscientists through symposia and lectures, some evidence has been gathered on how neuroscience was professionally useful. Since neuroscientists were able to substantiate neural changes due to learning and the diversity of human brains with a corpus of empirical data, the respondents reported neuroscience helped them to bolster up patience, optimism, and professionalism with their students. They added that their neuroscience understanding also boosted their credibility with other educators and parents as well as augmented their sense of education (Hook & Farah, 2013).

Before this paper goes further into the main discussion, let's have a little neuroscience 101 here – neurons are the basic cellular building blocks of the brain. A neuron is made up of dendrites, which receives signals from other neurons, the cell body, which processes those signals and the axon, a long "cable" that reaches out and interacts with other neurons' dendrites. When different parts of the brain communicate and coordinate with each other, they transmit electrical charges (nerve impulses) that travel down the axon of a neuron, eventually reaching the next neuron in the chain. Imagine a row of dominos stacked closely together – when a neuron fires, it is like knocking down the first domino in a long chain. This process repeats from neuron to neuron, until the nerve signals reach their destination. These firings happen at incredibly fast speeds. Another interesting fact about neurons is these are the only human cells that do not replicate when a person reaches a certain age, but neuroplasticity reveals that they grow new synaptic connections upon receiving new stimuli (i.e., learning). These connections are made permanent by constant exposure to the stimuli (i.e., constant training on a skill).

From the arguments, let's segue to the purpose of this paper – to formulate a form of science education philosophy that is founded on the neurological evidence of the impact of human learning. Therefore, suffice to propose that neuroeducation's philosophical viewpoint is to perceive learning is done by the neurological features of the brain will cause a favourable change in the corresponding region. The change is referred to the formation of new synaptic connections of neurons and the thickening of the myelin sheath of neurons (Appel, 2016; Kaller, Lazairi et al., 2017; Auer et al., 2018). The implication of such philosophy is this – learning is no longer interpreted merely as an abstract concept, but it has a physiological impact on the brain's structure. To support such a proposition, let's look at one of the most amazing brain studies on the formation of memory by Eric Kandel. As a psychoanalysis student, Eric Kandel became interested in learning the mechanism behind memory. By adopting a reductionist approach to his investigation, he successfully outlined the physiological basis of memory storage in neurons and that eventually led him to receive the 2000 Nobel Prize in Physiology or Medicine. There are two forms of memory, i.e., the complex forms of memory that require the hippocampus (known as the explicit memory storage) and the simple forms of memory (implicit memory storage) is the kind of memory that we will do rather automatically once we know it. Both forms of memory involve different mechanistic pathways. In the late 1950s, upon learning about the importance of the hippocampus to forge (and store) new memories through the case of HM who became amnesic after a bilateral removal in the hippocampal zone to halt the episodes of his epileptic attack (Milner et al., 1968), Eric Kandel and his partner Alden Spencer began their works with hippocampal pyramidal neurons.

Despite the laboratory success they achieved in finding electrophysiological evidence for action potentials in the dendritic trees of hippocampal neurons, they found it did not help explain why the hippocampus was important for explicit memory storage. In a conclusion, Eric Kandel thought it would be very difficult to study complex memory pathways in the hippocampal region of a complex organism and therefore shifted his focus to the simplest form – the implicit form of memory in a simpler organism. Therefore, our understanding of memory storage now is owed to his studies on a marine slug called Aplysia californica of which has much lesser neurons and is bigger if compared to human neurons. The slug has a robust reflex whereby it withdraws its gills in response to stimulation. Kandel experimentation on the sea slug revealed that when repeatedly stimulated the creature can learn to modify its reflex because of the consolidation of the regions where neurons are connected– the synapses (Frazier et al., 1967); Kosower, 2017). Perhaps, it is an absurd idea to compare the memory storage of slugs to the one in humans but based on our understanding of Darwinian evolution, we do know evolution is conservative in which if via natural selection it discovers that a certain set of mechanisms work well, evolution tends to retain those in perpetuity (Darwin, 2004; Campbell, 2017). Ergo, this is what one can extrapolate to *Homo sapiens* from *Aplysia californica* with the learning process.

In science education, the ability for students to retain scientific knowledge is an important basic skill. For the students to apply the knowledge to solve a real-world problem, they need to be able to keep the information in their heads. Therefore, it is paramount for science teachers to train the students to become skilful in retaining and recalling scientific facts so that they can move on to master other skills in science. In 1956, Bloom's Taxonomy was designed by Dr Benjamin Bloom to promote higher forms of thinking in education and until today it is one of the most useful guidelines in science education (Bloom, 1956). Based on the taxonomy, remembering or rote learning is situated at the lowest taxon. Perhaps the term "lowest taxon" gives a bad reputation to the skill that, in truth, is equally important as its higher taxon counterparts. The notion of rote learning being the lowest taxon should be replaced with the view that it serves as a vital base for all other higher cognitive skills to stand firmly. Ergo, without a strong base, it is difficult for a science student to climb up to higher cognitive domains. In this domain, therefore, science students take part in activities that get scientific information to be embedded in long-term memory storage.

After the ground-breaking discovery made by Kandel on the physiological basis of memory storage through his experiments on Aplysia californica, we have now gained insight into the biochemical process about neurons alterations associated with learning. It is rather fascinating to learn that the act of learning in remembering scientific facts in a science classroom involves new proteins to be synthesis in our brain. Upon learning new information in a science lesson, this information is coded by the brain as short-term memory. In the absence of the act of rehearsing or doing a conscious effort to remember the learned fact, the short-term memory will be forgotten in a matter of seconds. At the molecular level, the second messenger molecules are known as the cyclic adenosine monophosphate (cAMP) with its molecular formula $C_{10}H_{11}N_5O_6P$ are responsible for the formation of short-term memory during learning. The production of the second messenger cAMP is governed by a monoamine neurotransmitter serotonin which is mostly found in the digestive system, although it is also in blood platelets and throughout the central nervous system – CNS (Mawe & Hoffman, 2013). The nerve chemical is made from the essential amino acid tryptophan, and it helps to induce better sleep, for us to feel good and works wonders on our mood when we are feeling low. Serotonin also enhances learning, and it is linked with memory and neuroplasticity (Seyedabadi et al., 2014). When the level of cAMP is elevated in the presence of serotonin, it has been found that a cAMP-dependent protein kinase (protein kinase A) regulates a potassium channel that has an association with learning. Protein kinase A (PKA) is also responsible for the transcriptional control protein CREB (cAMP response element-binding protein). CREB is the protein that has been identified to be linked with long-term memory storage as it increases the number of synaptic connections upon activation (Yin & Tully, 1996; Kandel, 2012).

The vast and ongoing research on the biological basis of learning and memory storage gives science teachers a useful insight into the impact of learning on the brain. Educational psychologists have long-established the view that learning if effectively executed will result in a permanent change of behaviour and now neuroscience has provided us with the information that the changed behaviour corresponds to the permanent changes in the neural network. Science students who learn something new in the classroom, their neurons that transmit and receive information about the task become more and more efficient. Neurons that fire together conspires together. As the same learning continues, eventually it requires less effort for them to signal the next neurons about what is going on – these neurons have wired together (Beenhakker & Huguenard, 2009). Does practice lead to perfection? Of course, it is impossible to empirically justify "perfection" but what has been revealed by numerous brain research data, practice makes permanent. By encouraging science students to keep on practising certain scientific skills (e.g., laboratory skills), it is a process that promotes the production of myelin sheath in their brain. Myelinated neurons perform better. Myelin is the white matter (WM) of the brain and the fatty tissue that envelops around the long nerve fibres (axons) that extends out of the neurons. The insulation of axons with myelin increases the speed and strength of the nerve impulses by forcing the electrical charge to jump across the myelin sheath to the next open spot on the axon (Zatorre et al., 2012; Kaller et. al., 2017).

5. Conclusions

As a highly interdisciplinary research front, the objective of neuroeducation is to improve our understanding of human learning at the molecular level and henceforth improve human learning. This is achieved through the implementation of teaching and learning techniques that are espoused by empirical data from the field of brain research. On that account, the purpose of this paper is reiterated – to discuss neuroeducation as a philosophy in science education. As philosophy is built upon logic, neuroeducation is founded on the logic of scientific findings and data of the physiological impact of learning on neurocircuitries. Despite the criticisms and scepticism towards neuroscience, advocates of the field remain hopeful and relentlessly trying to bring the gap between neuroscience and education closer and closer in each breakthrough. Before the human brain and its mechanisms are well researched, learning difficulties like dyslexia, dyscalculia, autism, and ADHD (attention deficit hyperactivity disorder) were poorly understood and science students who were inflicted experienced unfavourable schooling atmospheres (Galaburda, 2010; Module, 2011; Fletcher et al., 2018). Books like "Brain Rules: 12 Principles for Surviving and Thriving at Work, Home, and School" (Medina, 2008), "Brain-Based Learning" (Jensen, 2000) and "Teaching Smarter with the Brain in Focus" (Armstrong, 2008) are arguably amongst the best easy-to-read materials made available for laymen. These books illustrate the pedagogical strategies grounded in neuroscience research that are practical and interesting for science teachers to adopt into their lessons.

Affirmative but not an alternative – that is the idea this paper is championing to establish neuroeducation as a philosophy of science education. This paper intends to mirror Kandel's reductionist method to describe the quality of neuroeducation as a philosophy. However, the effort is far from trying to dismiss the roles of the long-standing philosophies that have been driving our science education forward. Neuroeducation will be a great complement to the existing understanding of how we can optimise resources and manipulate the surroundings to forge the best ecosystem for the teaching and learning of science. Devonshire and Dommett (2010) outline two challenges needed to be overcome to bridge neuroscience and education effectively; firstly, a theoretical challenge that involves the shift in research mindset from the current focus that primarily focus on dysfunction to function but one that science teachers and neuroscientists can dictate together. Secondly, a practical challenge constitutes the need for teachers and neuroscientists to communicate with a shared language. Therefore, a commitment and collaboration amongst neuroeducation proponents will only see a positive trajectory for the field. Perhaps, the recognition of neuroeducation as a philosophy for science education will enable the field to produce more high-quality scientific literate individuals to bring the world another penicillin and Sputnik like scientific breakthroughs.

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