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Activating the Child's Own Natural Desire to Learn: Educational Neuroscience and the Development of Meaningful Learning Experiences

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ABSTRACT
Educators are on a constant quest for the ideal environment that is conducive to learning. In fact, at times, educators still encounter challenges related to the understanding of a lack of child's learning engagement or understanding of concepts presented to them, and the possible underlying reason for this. Many a time, educators resort to the assumption that the reason is that the student is intrinsically unmotivated or disinterested in learning. One area of study that could provide fresh knowledge in this regard is neuroscience. The design and configuration of the brain commence early in life and so learning opportunities offered in the early years of a child's life could have profound effects on the architecture learning facility of the brain. Hence, this provides educators with the opportunity to reflect on their pedagogy to understand how this can be improved to better suit the needs of the child in relation to how their brain is developing. The research presented in this paper provides educators with a clear picture on how their pedagogy can be improved to give the brain what it needs to prevent children from becoming disenchanted and disengaged in their learning environment. This paper combines two perspectives: desk research offering an understanding of brain plasticity and the biochemical interactions which connect learning and fun, and a narrative inquiry focused on delineating the connection between educational neuroscience and the development of purposeful learning experiences for young students.
keywords: Educational Neuroscience, Emergent Curriculum, Fun and Learning, Narrative Inquiry, Universal Design for Learning

1. Introduction

Every day, in schools across the globe, classroom practitioners and learners participate in the teaching-learning experience as actors, spectators, or as a mix of both. "Human beings are unique in their ability to learn through schooling" (Fischer et al, 2007, p. 1). It can be attested that in schools, teaching and learning are occurring, however, an understanding of what is exactly happening during the learning process is more elusive. According to Zull (2002, p. 2) "teaching is a mysterious process", with the primary reason being our lack of ability to precisely explain how it occurs. Are we any better at understanding how learning occurs? If the main aim of teaching is to facilitate learning, how can we understand teaching if we do not understand learning? Zull's assertion could be considered a valid justification for seeking to increase our knowledge of what happens during the learning process and for exploring how the optimal learning conditions to activate the learners' own natural desire to learn can be attained.

Throughout the years, academic inquiry has sought to unravel the complex interplay between the intricate mechanisms and architecture of the brain and how an understanding of these processes can shape the underlying fundamental components for meaningful learning to occur. In fact, Hart (1983) argues that,

> Education is discovering the brain, and that's about the best news there could be. Anyone who does not have a thorough, holistic grasp of the brain's architecture, purposes, and main ways of operating is as far behind the times as an automobile designer without a full understanding of engines (p. 21).

Discussions with educators in the attempt to engage in discussions related to the neuroscience of learning, often leads to observing them becoming disheartened, mostly due to the presumed complexity of scientific matter or challenging terminology such as "brain architecture" (Center on the Developing Child at Harvard University, 2021), "executive functioning" (Vanhear & Reid, 2019), and the umbrella term "neuroscience". The reason may be that, as observed in practice, educators find themselves ensnared in the daily set routine of school life and find it challenging to consider research as a pivotal factor to consider in their pedagogical reflections and professional practice. Such repetitive and unproductive routines hinder the educator from understanding how optimal outcomes as effective educators may be achieved if an understanding of brain development is grasped.

2. Materials and Methods

"Brains are built over time, and the foundations of brain architecture are constructed early in life" (Center on the Developing Child at Harvard University, 2016, p. 7). This means that the first years of a child's life may have long-term consequences for the development of the brain. This places an important onus on early years educators. A positive and well-crafted learning climate could provide a stimulus to young brains, providing the optimal environment for brain development. At the other extreme, a poor and unstimulating learning climate could adversely affect the progression of brain function. The purpose of this research is to comprehend the neural operations that occur during learning and to draw on relevant teaching pedagogies and strategies that offer effective learning experiences to young children. This research shares the hope of Amran et al. (2019) that "a better understanding of neuroscience may offer significant advantages for educators" (p. 341).

This research paper consists of two parts: desk-based research and a narrative inquiry. The foundation of this research is concerned with the science of learning, a branch of neuroscience relevant to education. It presents an overview related to neuroscience, brain function and the processes which occur during learning. In view of this and literature related to educational neuroscience, this paper suggests lessons that educators may find beneficial in their pursuit to provide students with a meaningful educational journey in the classroom. Additionally, this paper presents neuroscientific justifications for the fun imperative during learning, besides other philosophies of education, frameworks, and designs which if applied to a child-centered pedagogy might facilitate the activation of a child's own natural desire to learn.

As part of the narrative inquiry, three colleagues, a kindergarten educator and two key professionals in Early Years Education share their expertise and their experiences, linking educational neuroscience to flexible learning environments, the Universal Design for Learning, the Emergent Curriculum, and learning contexts that activate a child's own natural desire to learn. The experience of these professionals varies from key experts in the area of educational neuroscience, child development, teacher training and early childhood education practice.

A narrative inquiry was chosen to allow these participants to present their real-life experiences in a story-like manner related to their years in the field of education, both as practitioners and academics accordingly. They were invited to converse separately on the matter of educational neuroscience, brain development, pedagogy and learning in view of their own experience as educators. These were also the main emerging themes from the qualitative data acquired overarching the codes highlighted as explained below. The rich layers of information provided gave way for the interviewer to understand their point of view and link this to the data acquired from the desk-based research conducted (Clandinin & Connelly, 2000). This inquiry revealed different perspectives of how educational neuroscience informs pedagogy, and how acquiring insight on how the brain process and retains information as from a very young age whilst understanding how this development within the brain responds to learning process, stimuli and the general learning environment may in fact assist the educator to offer meaningful learning opportunities to students. The data acquired from the narrative inquiry was analysed using MAXQDA software. This allowed the researchers to code this qualitative data and analyse the content. This software provides a clear and comprehensive system to analyse the data acquired to make qualitative inferences, also by linking this to literature.

3. Results and Discussion

3.1. Introduction to Cognitive Neuroscience

Neuroscience can be defined as the study of the nervous system (Augustine et al., 2018). According to Kraft (2012, p. 386), the prefix "neuro" has become a fashionable, umbrella term and has been adopted by a wide range of disciplines, including: "neuroscience and neuromarketing, neurophilosophy and neuroethics, even neurotheology"; with the common understanding that "neuroscience has to do with the brain" (p. 387). Cognitive neuroscience is an area of research that focuses on how learning occurs in the brain (Gazzaniga et al., 2009). The increased interest in this area has resulted in excitement and speculation on the different ways neuroscience can be relevant to schools (Ansari et al., 2011; Flaisher-Grinberg & Ramsey, 2019; Guy & Byrne, 2013; Jaeggi & Shah, 2018; Varma et al., 2008). Other scholars are less convinced that neuroscience can be applied to classroom practice (Bruer, 2006, Kitchen, 2019). The term "neurononsense" was coined by Purdy (2006, p. 197) when referring to misconceptions about the application of neuroscience to education. Furthermore, Purdy (2006) advocated more caution when trying to find quick fixes from neuroscience to address challenges practitioners encounter in the classroom. Notwithstanding the varying perspectives and positionalities, educational neuroscience is a distinct research area, defined as: "a cross-disciplinary field where researchers work at the interface of education, psychology, and cognitive neuroscience" (Flobakk, 2016, p. 654).

Applying theoretical concepts through concrete examples in an early childhood classroom setting is that which is described by Rushton (2011) when he gives an example of two children playing with toy animals in a kindergarten class, categorising these animals as they deem fit. During play, different parts of the child's brain are in action through different 'neuro-pathways' (p. 92-93). This relates to the importance of providing young children with opportunities for interaction with stimuli in their environment, using their five senses. Rushton (2011) explains that 'light rays enter the eyes' pupils, convert to an electrochemical impulse behind the retina, and follow neurons to the thalamus, which sends the signal to the occipital lobe's millions of cells, each one designed for a specific task' (p. 93). This occurs when for example a child is exploring shapes, texture, colours, or shades of colours provided in a learning opportunity in an educational setting. Using their hands to feel different textures, for example, means that the nerves in their hands are sending electrochemical messages to the brain, through the arm, to the spinal column and to the thalamus. This mass in the brain, which is mostly comprised of grey matter, processes the messages received and forwards these signals to the motor cortex which is found in the midline centre of the brain. It is this process which allows the child to take a decision on in which pile they should put the animals they are playing with, according to how they decide to categorise them. This activates the prefrontal lobe, which is in fact the decision-making centre of the brain.

3.2. Understanding Learning as a Process

Humanity has been captivated by the brain since the dawn of time. Aristotle (384–322 BC) studied the relationship between brain and body size in many species and concluded that the ratio was highest in species with more advanced cognitive abilities, such as humans (Ward, 2015). Nowadays we know that the brain is made up of nerve cells, called neurons (Morris & Fillenz, 2003). There are trillions of neurons in the brain (National Research Council et al., 2000). Signals pass along neurons and the point where one signal passes from one neuron to another is called a synapse (Wolfe, 2010). Learning occurs in the brain, more specifically, learning brings about changes in the neurons in the brain. Long and Corfas (2014) summarise what happens during learning:

> Learning triggers neural changes in the brain that contribute to information acquisition and memory formation, including the activity and strength of existing synapses, the formation of new synapses, and possibly the birth of new neurons (p. 298).

Furthermore, learning might also bring about changes in the myelin sheath, which covers each neuron (Long & Corfas, 2014). Neurons change during learning, and this means that the brain changes during learning; the ability of the brain to change is referred to as brain plasticity (Owens & Tanner, 2017).

The narrative inquiry conducted with two academics and one practitioner in the field of education unveiled that knowledge related to the process occurring in the brain during learning are only known to them through research conducted independently and not as part of the core curriculum of a teaching training programme. Whilst this may be changing nowadays, the only reference to brain development in teacher training was that referred to through modules related to psychology. The discussion also delved into their own personal experiences as students and how they felt disenchanted at times in the classroom, for one reason or another. In fact, Vuilleumier (2005) concurs and states that the child’s wellbeing needs to be addressed and nourished as disregarding this will affect the child’s attention which is not conducive to learning.

3.3. Emotions, Social Interactions and Learning

Research shows that learning does not occur in a vacuum; various factors can condition learning. Emotions directly influence the learning process (Teruel, 2013); this may be the result of the way they can affect attention and memory (Martínez Pérez & Salvador Bertone, 2019). Neville (2013) claims that “our brains are social” (p. 17). Several studies seem to confirm this assertion and underscore the importance of social interactions in learning, with positive social interactions having a beneficial effect on the learning process (Immordino-Yang & Faeth, 2010; Kuhl, 2011; Nelson et al., 2007). Research conducted by Perry and Pollard (1997) showed that neglect in childhood had a detrimental effect on the neurodevelopment of young children. Through neuroimaging, their study revealed the physical effects of neglect on the brain. The following image (Figure 1) shows a comparison between the brain scan of a normal child (on the right) and the scan of a child who suffered severe sensory deprivation (on the left). In the latter, it can be observed that the cortex is shrunken (Perry & Pollard, 1997). The cortex is responsible for high-level functions such as thinking, memory, learning, problem-solving and emotions (Roberts, 2014).

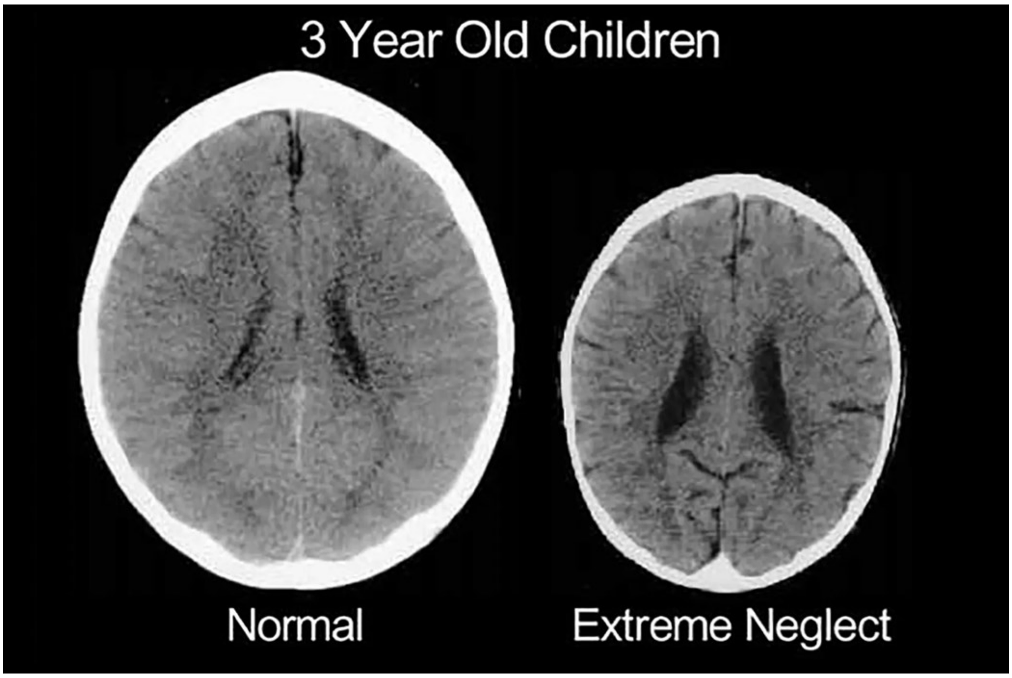

Figure 1. Brain scan of a normal child and of a child suffering severe neglect
Note. From Perry, B. D. Baylor College of Medicine, reproduced in Perry, B. D. and Pollard, D. (1997, p. 6). http://www.sakkyndig.com/psykologi/artvit/perry1997-2.pdf

Keeping in mind that all children have a unique brain which thinks, feels, and learns in different ways, Rushton (2011) presents four basic principles, in simple terms, which refer to how one can tap into the mental, emotional, social, and physical life of these young beings; whilst providing an environment and the stimulation offered within allowing brain development to effectively occur. Such a learning environment should be facilitated by the educator, which role includes setting the scene in which children learn to learn, can make their own choices, and take decisions whilst expressing their emotions and feelings as part of the development of these skills. Above all, the learning environment the educator creates should be one in which inquiry-based learning strategies linked to real-life, hands-on learning experiences prevail, allowing the student to feel comfortable to ask questions and become critical thinkers. What educators need to understand is that such principles in fact emerge from scientific studies of the brain. However, the narrative inquiry with participating colleagues revealed that most educators, both newly qualified and others with experience struggle to link research to practice. This is sustained by Horvath et al. (2017) who finds it concerning that a lack of transference from theoretical scientific research to the implementation of strategies for meaningful learning in the classroom is observed in the pursuit to impact educational development effectively.

3.4. Fun and Learning

Fun has a direct effect on learning (Willis, 2007). Liu et al (2017) reviewed neuroscience and biological literature and concluded that: "Joy, it seems, has an important relationship to our propensity to learn" (p. 6). Furthermore, field studies and neuroscientific research confirm the link between fun and learning. Tisza and Markopoulos (2020) conducted research on the possible link between learning and fun. Their study examined the self-reported learning that occurred in 86 children aged between nine and 12 during a two-hour workshop on coding, conducted in a playful environment. The researchers also developed a tool to enable the level of fun to be measurable and comparable. Their results showed that although fun did not have a direct effect on self-reported learning, it positively and significantly influenced the students' attitudes to learning about coding.

This relates to what emerged from our narrative inquiry in relation to the introduction and implementation of the emergent curriculum as a philosophy of education in the early childhood years of education in Malta. Our interviewees sustained that it is crucial that the educator prioritises the image of the child and their needs by getting to know them as individuals, observing and deciphering what their interests are and creating stimulating learning opportunities which the children find fun.

3.4.1. The Effect of Fun on the Brain

As mentioned earlier, the synapse is the intersection where the impulse from one neuron passes on to the next neuron. At the synapse, electrical impulses or neurotransmitters allow the transmission of signals from one neuron to another (Roberts, 2014). Figure 2 depicts how a signal is transferred from one neuron to the next one.

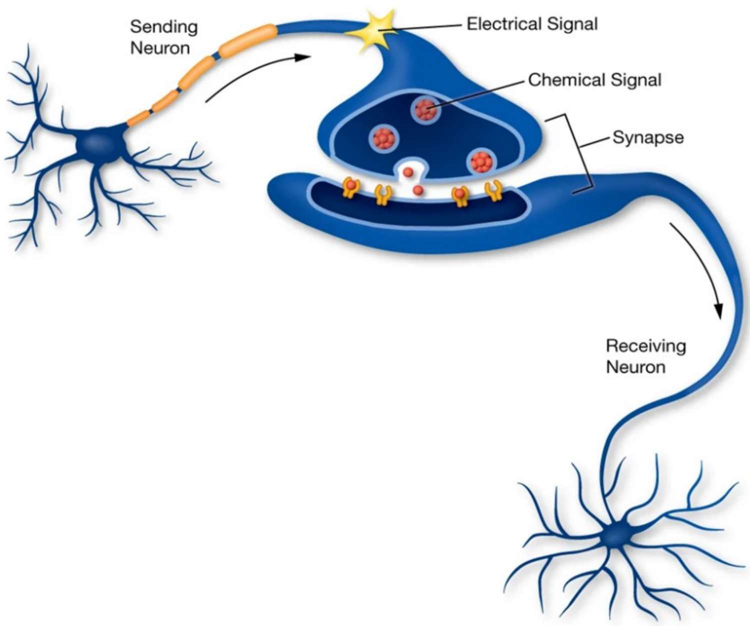

Figure 2. Transmission at the Synapse
Note. The synapse.
From Learn.Genetics. (n.d.) *Neurons transmit messages in the brain*.
https://learn.genetics.utah.edu/content/neuroscience/neurons

Pleasant sensations release the neurotransmitter dopamine (Willis, 2007) which, in turn, increases motivation and learning (Berke, 2018). Dopamine also has a positive effect on memory retention (Wise, 2004). Fun is often associated with novel situations; whenever there is an element of surprise, the neurotransmitter acetylcholine is released (Owens & Tanner, 2017). Acetylcholine brings about synaptic plasticity (Picciotto et al., 2012) which is needed for learning to occur. The chemistry and biology behind the effect of fun on learning further validate the importance of prioritising the fun component when planning learning activities.

Therefore, this reinforces the fact that the acquisition of knowledge alone does not lead to meaningful learning. In fact, conversations during our narrative inquiry led to the notion that the Universal Design for Learning (UDL) (Meyer et al., 2014), which is a framework founded on the neuroscience behind how learning occurs to support all learners, can optimize teaching and learning. Linking research to such a framework gives educators a better understanding of how learning can occur effectively based on three vital components: 'thinking', 'doing' and 'feeling'. The acquisition of knowledge and 'thinking' occur at the back of the brain; that which is exhibited as actions and skills through 'doing', occurs at the front of the brain; whilst the affective networks, relating to 'feeling', affect both the 'thinking' and the 'doing'. Hence, as research suggests that these three sectors are simultaneously engaging in interaction, it is crucial that they are included in every learning opportunity offered to children. In fact, the narrative inquiry produced reflections related to past instances during early childhood practice which resulted in a realization that pondering on why certain learning experiences did not prove effective was because either one of the 'thinking', 'doing' or 'feeling' components were left out or separated. Whilst on the other hand, when concurrently employing these components, children were enchanted, engaged, and learning occurred.

The narrative inquiry also delved into the fact that the fun element transpires from a child-centred pedagogy from the earliest years of education. This stems from the idea of creating a 'brain-compatible' classroom enabling the link between stimulating positive emotions and learning (Rushton, 2011, p. 92). Harris (2013) states that the educator should be capable of identifying the children's interests and motivations and the wisdom to ascertain their skills and dispositions to ensure that their pedagogy is geared towards supporting them to reach set learning outcomes and not on a pedagogy focused on instruction. This concurs with that which emerged from narrative inquiry, as it was sustained how important it is that educators do not have a mindset which revolves around what they deem fit. This bottom-up approach to inform the teaching and learning process is also acknowledged by Rushton (2011) who states that as emotions depend on the different levels of neurochemicals in the brain, such as dopamine, as explained above, a child's motivation to engage in learning also depends on how the levels of these neurochemicals fluctuate. The sensation of fun increases the release of the neurotransmitter's dopamine and acetylcholine, which play a key role in synaptic transmission in the brain and hence in learning. Therefore, it is that which is presented to them as part of their learning experience which will impact how the brain will react to the learning process, hence stimulating the child's intrinsic inclination towards learning.

4. Conclusions

Insights into neuroscience can provide a new impetus for educators to offer fresh learning environments and experiences to their learners. This paper presents an understanding what of happens in the brain during learning to further motivate and recommend to classroom practitioners to incorporate fun in the classroom whilst implementing a child-centred pedagogical approach to activate young children's natural desire to learn, as one strategy, even if effective for one child, may not be applicable to all children. Therefore, first and foremost this paper recommends that educators continuously engage in reflective practices. These may be either done individually as part of a self-reflective process or induced by the responsible educational organizations. It is crucial that educators align specific pedagogical strategies to facilitate processes occurring in the brain of a child. In view of a child-centred approach as explained above, the following recommendations are suggested.

It is of paramount importance that educators adopt a scaffolded learning approach, whereby tasks presented match the child's developing abilities and the complexity of such tasks are adjusted accordingly to foster a sense of achievement. Learning opportunities planned should promote experiential learning using a hands-on approach linked to real-life experiences, allowing children to actively explore concepts presented to them. Such opportunities should also enable children to become engaged through the integration of multisensory modalities exposing them to various stimuli, namely auditory, visual, tactile, and kinesthetic. The Universal Design for Learning's framework provides guidelines for educators in this regard for educators to proactively meet the needs of all learners. Educators may also consider transdisciplinary learning which provides the child with the opportunity to make connections between concepts. Incorporated within these approaches, it is recommended that the educator's position is one which enables cognitive flexibility, which means that activities organized in the learning environment encourage children to develop their thinking and problem-solving skills; and social interaction to enhance the child's communication skills. This suggests that is crucial that educators steer clear of simple instruction during learning opportunities and rather facilitate the learning process through effective questioning techniques and immediate and constructive feedback.

Above all, drawing on neuroscience literature, a relevant lesson for classroom practice is that fun during learning which encompasses approaches presented in this paper and the educator's acquisition of knowledge on brain development and process occurring within, could enhance and accelerate the learning process and it could positively impact memory retention. This is most prominent during the first five years of a child's life, during which billions of neurons are being connected for development to occur (Miller & Cummings, 2007).

References

Amran, M. S., Rahman, S., Surat, S., & Bakar, A. Y. A. (2019). Connecting neuroscience and education: Neuroscience findings for better instructional learning. *Journal for the Education of Gifted Young Scientists, 7* (2), 341-352. https://doi.org/10.17478/jegys.559933

Ansari, D., Coch, D., & De Smedt, B. (2011). Connecting education and cognitive neuroscience: Where will the journey take us? In K. E. Patten & S. R. Campbell (Eds.), *Educational neuroscience: Initiatives and emerging issues* (pp. 36–41). Wiley-Blackwell. https://doi.org/10.1002/9781444345827.ch6

Augustine, G. J., Fitzpatrick, D., Hall, W. C., Hayden, B., LaMantia, A., Mooney, R. D., Platt, M. L., Purves, D., Wang, F., & White, L. E. (2018). Studying the nervous system. In D. Purves, G. J. Augustine, D. Fitzpatrick, W. C. Hall, A. LaMantia, R. D. Mooney, M. L. Platt & L. E. White (Eds.), *Neuroscience* (6th ed., pp. 1–29). Oxford University Press.

Berke, J. D. (2018). What does dopamine mean? *Nature Neuroscience*, 6(2), 1–7. https://doi.org/10.1038/s41593-018-0152-y

Bruer, J. T. (2006). Points of view: On the implications of neuroscience research for science teaching and learning: Are there any? A skeptical theme and variations: The primacy of psychology in the science of learning. *CBE life sciences education, 5*(2), 104–110. https://doi.org/10.1187/cbe.06-03-0153

Center on the Developing Child at Harvard University. (2016). From best practices to breakthrough impacts: A science-based approach to building a more promising future for young children and families. http://www.developingchild.harvard.edu.

Center on the Developing Child at Harvard University. (2021). Three principles to improve outcomes for children and families, 2021 Update. http://www.developingchild.harvard.edu

Clandinin D.J. & Connelly F.M. (2000). Narrative inquiry: Experience and story in qualitative research. Jossey-Bass Publishers. https://doi.org/10.1016/B978-008043349-3/50013-X

Fischer, K. W., Daniel, D. B., Immordino-Yang, M. H., Stern, E., Battro, A., & Koizumi, H. (2007). Why mind, brain, and education? Why now? *Mind Brain and Education, 1* (1), 1-2. https://doi.org/10.1111/j.1751-228X.2007.00006.x

Flaisher-Grinberg, S. & Ramsey, M. (2019). The neuroscience of fun! Creating an avenue of public education through academia-community partnership. *IMPACT: The Journal of the Center for Interdisciplinary Teaching and Learning. 8*(2)30-36. http://open.bu.edu

Flobakk, F. R. (2016). Educational neuroscience and reconsideration of educational research. *Pedagogika, 66* (6), 654-671. http://pages.pedf.cuni.cz/pedagogika/

Gazzaniga, M. S., Doron, K. W., & Funk, C. M. (2009). Looking toward the future: Perspectives on examining the architecture and function of the human brain as a complex system. In M. S. Gazzaniga (Editor-in-Chief), *The cognitive neurosciences* (pp. 1247–1254). The Mitt Press. https://doi.org/10.7551/mitpress/8029.003.0111

Guy, R., & Byrne, B. (2013). Neuroscience and learning: Implications for teaching practice. *Journal of experimental neuroscience, 7*, 39–42. https://doi.org/10.4137/JEN.S10965

Harris, J., Spina, N., Ehrich, L., & Smeed, J. (2013*). Literature review: Student-centred schools make the difference.* Australian Institute for Teaching and School Leadership.

Hart, L. (1983). *Human brain and human learning*. Longman.

Horvath, J. C., Lodge, J. M., & Hattie, J. (Eds). (2017). *From the laboratory to the classroom: Translating science of learning for teachers*. Routledge. https://doi.org/10.4324/9781315625737

Immordino-Yang, M. H., & Faeth, M. (2010). The current impact of neuroscience on teaching and learning. In D. A. Sousa (Ed.), *Mind, brain, & education: Neuroscience implications for the classroom* (pp. 69–84). Solution Tree Press.

Isen, A. M., Daubman, K. A., & Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. *J. Pers. Soc. Psychol., 52*, 1122–1131. https://doi.org/10.1037/0022-3514.52.6.1122

Jaeggi, S. M., & Shah, P. (2018). Editorial special topic: Neuroscience, learning, and educational practice – Challenges, promises, and applications. *AERA open, 4*(1). https://doi.org/10.1177/2332858418756053

Kitchen, W. H. (2019). *Philosophical reflections and neuroscience and education.* Bloomsbury.

Kuhl, P. K. (2011). Early language learning and literacy: Neuroscience implications for education. *Mind, brain and education: The official journal of the International Mind, Brain, and Education Society, 5*(3), 128–142. https://doi.org/10.1111/j.1751-228X.2011.01121.x

Learn.Genetics. (n.d.) *Neurons transmit messages in the brain.* https://learn.genetics.utah.edu/content/neuroscience/neurons

Liu, C., Solis, L., Jensen, H., Hopkins, E. J., Neale, D., Zosh, J. M., Hirsh-Pasek, K., & Whitebread, D. (2017). *Neuroscience and learning through play: A review of evidence.* White paper. The LEGO Foundation. https://doi.org/10.13140/RG.2.2.11789.84963

Long, P., & Corfas, G. (2014). Neuroscience. To learn is to myelinate. *Science*, *346*(6207), 298–299. https://doi.org/10.1126/science.1261127

Martínez Pérez, J. F., & Salvador Bertone, M. (2019). Cognitive neuroscience and how students learn: Hype or Hope. *International journal of psychological research, 12*(1), 6–8. https://doi.org/10.21500/20112084.4047

Meyer, A., Rose, D. H., & Gordon, D. (2014). Universal design for learning: Theory and practice. CAST.

Miller, B. L. (2007). The human frontal lobe: An introduction. In B. L. Miller & J. L. Cummings (Eds.), *The human frontal lobes: Functions and disorders*. 3–11. The Guilford Press.

Morris, R., & Fillenz, M. (2003). *Neuroscience: Science of the brain – An introduction for students*. The British Neuroscience Association.

National Research Council, Division of Behavioral and Social Sciences and Education, Board on Behavioral, Cognitive, and Sensory Sciences, and Committee on Developments in the Science of Learning, with additional material from the Committee on Learning Research and Educational Practice. (2000). *How people learn: Brain, mind, experience, and school: Expanded edition*. National Academies Press.

Nelson, C., Zeanah, C. H., Fox, N. A., Marshall, P. J., Smyke, A. T., & Guthrie, D. (2007). Cognitive recovery in socially deprived young children: The Bucharest early intervention project. *Science, 318*, 1937–1940. https://doi.org.10.1126/science.1143921

Neville, B. (2013). The enchanted loom. In N. Newberry, A. Gallant, & P. Riley (Eds), *Emotion and school: Understanding how the hidden curriculum influences relationships, leadership, teaching and learning* (pp. 3-24), Emerald Group Publishing Limited. https://doi.org/10.1108/S1479-3687(2013)0000018005

Owens, M. T., & Tanner, K. D. (2017). Teaching as brain changing: Exploring connections between neuroscience and innovative teaching. *CBE Life Sciences Education, 16*(2), 1–9. https://doi.org/10.1187/cbe.17-01-0005

Perry, B. D., & Pollard, D. (1997). Altered brain development following global neglect in early childhood. *Society for Neuroscience: Proceedings from Annual Meeting,* New Orleans, 1997. http://www.sakkyndig.com/psykologi/artvit/perry1997-2.pdf

Picciotto, M. R., Higley, M. J., & Mineur, Y. S. (2012). Acetylcholine as a neuromodulator: Cholinergic signaling shapes nervous system function and behavior. *Neuron*, 76(1), 116–129. https://doi.org/10.1016/j.neuron.2012.08.036

Purdy, N. (2008). Neuroscience and education: How best to filter out the neurononsense from our classrooms? *Irish Educational Studies, 27* (3), 197-208. https://doi.org/10.1080/03323310802242120

Roberts, M. (2014). *Biology – A Functional Approach* (4th ed.). Nelson Thornes.

Rushton, S. (2011). Neuroscience, early childhood education and play: We are doing it right! Early Childhood Educ. J., 39, 89–94. https://doi.org/10.1007/s10643-011-0447-z

Teruel, F. M. (2013). What is an emotion? *Arbor, 189* (759), 1–6. https://doi.org/10.3989/arbor.2013.759n1003

Tisza, G. & Markopoulos, P. (2021). Understanding the role of fun in learning to code. *International Journal of Child-Computer Interaction, 28*(2), 1-11. https://doi.org/10.1016/j.ijcci.2021.100270

Vanhear, J., & Reid, A. (2019). *Addressing learner variability through executive function as a preventive measure for early school leaving. Early leaving from education and training – The way forward.* MEDE.

Varma, S., McCandliss, B. D., & Schwartz, D. L. (2008). Scientific and pragmatic challenges for bridging education and neuroscience. *Educational Researcher, 37*(3), 140–152. https://doi.org/10.3102/0013189X08317687

Vuilleumier, P. (2005). How brains beware: Neural mechanisms of emotional attention. Trends in cognitive sciences, 9, 585–594. https://doi.org/10.1016/j.tics.2005.10.011

Ward, J. (2015). *The student's guide to cognitive neuroscience* (3rd ed.). Psychology Press. https://doi.org/10.4324/9781315742397

Willis, J. (2007). The neuroscience of joyful education. *Educational Leadership, 64*(9), 1–5. https://www.ascd.org/el/articles/the-neuroscience-of-joyful-education

Wise, R. A. (2004). Dopamine, learning and motivation. *Nature Reviews Neuroscience*, *5*(6), 1–12. https://doi.org/10.1038/nrn1406

Wolfe, P. (2010). *Brain matters: Translating research into classroom practice* (2nd ed.). ASCD.

Zull, J. E. (2002). *The art of the changing brain: Enriching the practice of teaching by exploring the biology of learning.* Stylus Publishing.