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Maria Montessori : A Visionary Whose Insights Align With Neuroscience

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Résumé

L'approche éducative de Maria Montessori, fondée sur l'observation et l'expérimentation de l'enfant, reste l'une des formes d'éducation alternative les plus anciennes et les plus largement adoptées. La recherche contemporaine en neurosciences valide de plus en plus les principes de Montessori, mais établir un pont solide entre ces deux domaines reste difficile. Des facteurs tels que des objectifs différents, une terminologie différente et l'absence d'un cadre de collaboration entravent leur synergie. Cette *Perspective* explore l'intersection entre les résultats des neurosciences et la philosophie éducative de Montessori, structurée en cinq domaines clés : Premièrement, la présentation de quelques idées neuroscientifiques : Une exploration de divers aspects neuroscientifiques liés à l'apprentissage, au développement du cerveau et à la cognition. Deuxièmement, un bref historique des contributions de Maria Montessori : un aperçu historique de la vie, de l'œuvre et de la méthodologie éducative de Maria Montessori. L'identification des domaines où les neurosciences et les principes Montessori se croisent est ensuite présentée, notamment l'importance du mouvement, le développement émotionnel, l'apprentissage social, le rôle de l'environnement préparé, la transition des concepts concrets aux concepts abstraits, l'autorégulation, les périodes sensibles et la mémoire. Tout en reconnaissant les défis et les limites de la recherche en éducation Montessori, cette *Perspective* met l'accent sur les preuves de plus en plus nombreuses de

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l'alignement des principes Montessori sur les résultats des neurosciences. Cela souligne la pertinence durable de l'approche éducative holistique de Montessori et met en lumière les avantages potentiels d'une collaboration plus approfondie entre ces domaines, dans le but d'améliorer les pratiques éducatives et de favoriser des expériences d'apprentissage complètes pour les enfants.

Mots clés : Montessori, apprentissage, mémoire, neuroscience cognitive, neuroscience affective, école, enfant.

Abstract

Maria Montessori's approach, based on observation of and experimentation with children's learning processes, remains one of the longest-standing and widely embraced forms of alternative education. Contemporary neuroscience research increasingly validates Montessori's principles, yet a robust bridge between these two fields remains elusive. Factors such as differing goals, terminology and the lack of a collaborative framework hinder their synergy. This literature review explores the intersection between neuroscience findings and Montessori's educational philosophy, structured into five key areas. The *Perspective* first presents various neuroscience insights: an exploration of aspects related to learning, brain development and cognition. Second, a brief background on Maria Montessori's contributions: a historical overview of Maria Montessori's life, work and educational methodology. Third is the identification of the areas where neuroscience and Montessori principles intersect, including the importance of movement, emotional development, social learning, the role of the prepared environment, the transition from concrete to abstract concepts, self-regulation, sensitive periods and memory. Finally, while acknowledging the challenges and limitations in researching Montessori education, this review emphasises the growing evidence that supports the alignment of Montessori principles with neuroscience findings. This underscores the enduring relevance of Montessori's holistic education approach and highlights the potential benefits of a deeper collaboration between these fields, to enhance educational practices and promote comprehensive learning experiences for children.

Keywords: Montessori, Learning, memory, cognitive neuroscience, affective neuroscience, school.

1. INTRODUCTION

Maria Montessori's educational approach, developed in the 20th century through rigorous experimentation with and keen observation of children's learning processes, stands as one of the most widely embraced forms of alternative education in the world, with an

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enduring legacy (Lillard, 2019). Today, as neuroscience delves deeper into unravelling the intricate workings of the human brain, many of Montessori's visionary ideas have found substantial validation (Fabri & Fortuna, 2020). It has become apparent that connecting these two distinct branches, education and neuroscience, could mutually benefit educators and scientists (Ansari, 2005).

However, a robust link between neuroscience and education has not yet been firmly established. Several factors impede their alignment. These include different goals, disparities in terminology and levels of description (Bruer, 1997; Rogers & Thomas, 2023), and the absence of an established framework to facilitate collaboration (Ansari, 2005; Bruer, 1997; Jamaludin et al., 2019). Moreover, much of the conducted research on the learning brain has primarily involved adult participants (Ansari, 2005).

Hence, the goal of this *Perspective* is to identify and explore the intersections between the latest neuroscientific findings and Montessori's foundational educational philosophy and methods. Neuroscientific results often stem from meticulous laboratory scans and experiments, while Montessori's principles were carefully generated through close observation of children's behaviour and learning experiences. The structure of this work will be presented as follows:

1. Presentation of various aspects related to learning-derived neuroscience.
2. Presentation of and background information on Montessori's education method.
3. Examination of the salient points of intersection between the two aforementioned dynamic domains.

2. METHODS

The current *Perspective* aims to synthesise the existing knowledge on the alignment between Montessori's principles and neuroscientific insights, in doing so endeavouring to establish the connections between the principles Montessori advocates and accepted understanding of how the brain learns. To achieve this, a comprehensive search was conducted using electronic databases known for their academic rigour and relevance to educational aspects and practices, as well as educational and cognitive neuroscience.

Conducted in the period June to September 2023, the literature search encompassed various electronic databases, among them PubMed, Sage Journals, the Centre for Educational Neuroscience at University College London, Birkbeck University of London, the UCL Institute of Education, Scientific American and many others. Many articles were found based on keywords such

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as 'Montessori', 'Neurosciences', 'Mind', 'Learning', 'Brain', 'Sensitive Periods' and associated combinations. The review incorporated a spectrum of resources such as podcasts, books, scientific reports, magazines, systematic review articles and meta-analyses, all of which were published in recent years and are available in either English, French or Greek.

Once the resources were identified, they were systematically reviewed and the relevant information was extracted. This process included capturing key concepts, findings and insights that addressed the alignment between Montessori's principles and neuroscientific findings. Then, the extracted data were synthesised through thematic analysis to identify common themes, patterns and connections across the selected resources.

It is necessary to recognise the limitations of this *Perspective*. First, the ever-evolving nature of Montessori educational settings and neuroscientific research implies that certain recent advancements might not be fully represented within the chosen timeframe. Additionally, Montessori's work has been documented in numerous books and has undergone various translations that could potentially alter the original meaning and intent of her words.

3. DISCUSSION

3.1. Neuroscience

Neuroscience is the study of the nervous system, encompassing its structure, function and relationship to behaviour and cognition throughout life. Among the 40 disciplines and subdisciplines of neuroscience (Jolles & Jolles, 2021), educational neuroscience focuses on the science of learning. Positioned at the intersection of neuroscience, psychology, education, social theory and even computer science (Jamaludin et al., 2019), this interdisciplinary field aims to bridge the gap between these domains. Its fundamental goal is to identify and develop effective techniques that teachers and students can use to enhance the learning process. According to Battro et al. (2008), the domains of education and human development should be viewed through a 'dynamic system'. This phrase typically refers to a system in which elements interact and change over time, and often exhibit complex and non-linear behaviour. Dynamic systems are frequently studied in various fields, including mathematics, physics, biology, and economics, to understand how variables or components within the system evolve and influence each other (Van Geert and Steenbeek in Battro et al., 2008).

Until the end of the 20th century, the link between neuroscience and education seemed too challenging due to the inherent complexities of conducting research within

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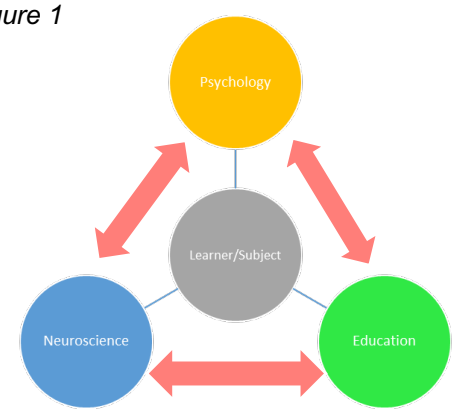
classroom settings (Franco & Robson, 2023). Cognitive psychology played a pivotal role in serving as a bridging link, which contributed to educational practices (Bruer, 1997). Figure 1 depicts a schematic representation illustrating the interconnection between the fields of psychology, education, and neuroscience, highlighting their collective contributions in support of the learner.

Figure 1



The human brain, a complex organ, has evolved to facilitate thinking and eventually learning. However, these two mechanisms are built upon more crucial functions such as survival, sensory development and social interaction (Rogers & Thomas, 2023). The development of the brain depends on both genetic and environmental factors, termed 'predisposition' in neuroscience.

While the genetic blueprint guides brain development, is encoded in the genes and inherited across generations, experiences and interactions after birth can alter the cerebral structure (Singer in Battro et al., 2008; Fahmy, 2022; Knudsen, 2004). Alongside early-life experiences, access to nutritious food and quality sleep significantly impact brain development (Rogers & Thomas, 2023). Moreover, a family's socioeconomic status also has an impact on a child's physical and psychological development (Courtier et al., 2021).

A rich physical and relational environment enables the creation of synapses (Bruer, 1997; Jamaludin et al., 2019; Masson, 2020). Synapses are the connections between nerve cells (neurons) that allow them to communicate with one another. They play a crucial role in the transmission of information in the nervous system. In contrast, stress, particularly during critical periods of growth, such as prenatal and early childhood, can impede synapse formation and neurogenesis.

Another important function of the brain is neuroplasticity; the brain's ability to modify neuronal connections (synapses) in response to learning, experience, activity, injury or disease throughout one's life (Larisson in Lyman, 2016; Masson, 2020).

> *At the time of birth, all neurons are in place and the basic connections, especially those bridging long distances are formed. It is only after birth and during the following years that the functional architecture of the brain attains its final complexity (Singer in Battro et al., 2008, p. 100).*

As far back as 1949, Canadian psychologist Donald O. Hebb, regarded as the father of neuropsychology, put forward a neurophysiological explanation for learning and memory based on a fundamental principle:

When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased (Hebb, 1949, p. 62).

This statement offers an early glimpse into the concept of neuroplasticity. This statement was taken years later by Carla Shatz in her work, 'The Developing Brain', and was simplified to a rhyme found in many neuroscientific discussions:

Cells that fire together wire together (Shatz, 1992, p. 64).

Abigail Larrison (in Lyman, 2016) notes that neuroplasticity is dependent on activity or experience. This implies that the brain's adaptability and reorganisation hinge on the extent of engagement and exposure to diverse stimuli or experiences, and that intelligence is not fixed at birth.

During the process of brain maturation, active synapses and connections between neurons are enhanced, whereas inactive synapses become weaker and are eliminated. This phenomenon is known as 'synaptic pruning'. It plays a significant role in learning and memory recall and takes place during childhood and adolescence (Fahim, n.d.; Shatz, 2020).

'Cognition' refers to the mental processes involved in acquiring, storing, transforming, using, and communicating information. It encompasses a variety of thinking facets, such as perception, attention, memory, reasoning, problem-solving, language comprehension and decision-making. Cognition is fundamental to the learning, problem-solving and decision-making processes, and plays a critical role in how individuals perceive and interact with their surroundings.

Intelligence, defined as the capacity to acquire, adjust to, influence, and make choices regarding one's surroundings, is not fixed from birth and has the potential to develop over the course of a lifetime and across generations(Sternberg, 2012). The varying characteristics of children arise from variations in their upbringing and the values instilled by their parents.

3.2. Historical and biographical background on Maria Montessori

Maria Montessori was born in Italy in 1870. She became one of the first female physicians of her time, after having attended the medical school at the University of Rome. Following her graduation, she worked at hospitals and

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psychiatric clinics, in which she realised that children with learning difficulties could indeed be educated to a certain degree, which was not a practice at the time. She believed that all children are capable of learning when provided the proper means and placed in an environment tailored to their age and needs (Montessori & Montessori, 2007).

In 1907, she established a school for young children, aged 3 to 6 years, from low-income families in the San Lorenzo district of Rome. While not employing a particular teaching method, she relied on the observation and interpretation of the children's behaviour to guide her in modifying and designing materials through which the children would learn (Marshall, 2017; Montessori, 1966; Montessori & Montessori, 2007).

The culmination of her efforts is what we recognise today as the Montessori method. Although it did not exist in the form as we know it during her lifetime, there are recognisable elements. For instance, based on her observations, Montessori saw the significance of repetition. Children would engage in the same activity repeatedly until they mastered the skill and fulfilled their needs.

> *They repeated the performance again and again without having any longer an external aim in doing so. It was by an inner need that they went on washing their hands that were already clean. The same thing happened on many other occasions; the more accurately an exercise was taught in all its details, the more it seemed to become a stimulus to an endless repetition of the same exercise (Montessori, 1966, p. 126).*

Another crucial component of the method, which is today often taken for granted, is the freedom to choose activities. After observing that the children were capable of independently selecting activities – with these choices even leading to remarkable levels of concentration and motivation – Montessori abandoned the use of locked cupboards and the role of adults as mediators between the materials and the child (Montessori, 1966; Tourret, n.d.).

> *I have observed that the child, on condition that he is granted the freedom to work, learns, becomes cultured, absorbs knowledge and gains experiences that become embedded in his spirit. Like seeds planted in fertile ground, they soon germinate and bear fruit (Montessori, 2019, p. 96).*

According to Maria Montessori, children begin perceiving their environment and absorbing it through their senses even from within the womb. She used the term 'absorbent mind' to describe children's innate ability to assimilate the elements of their environment. The absorbent mind is the capacity of young children to learn without effort (Hartrich in

Lyman, 2016). Based on her observations, Montessori asserted that at a certain age all children display similar needs, referred to as 'sensitive periods' (Tourret, n.d.).

The education that Maria Montessori aimed to provide was a form of 'aid to life' (Tourret, n.d.). Indeed, today, the accumulation of a standardised set of facts and formalities is widely considered an outdated practice. Education's goal is to furnish individuals with the means to understand the world and unleash their potential in a holistic sense that encompasses intellectual, physical, emotional and social aspects (Marshall, 2017).

3.3. Where neuroscience and Montessori intersect

There have been some research projects within Montessori schools, however, they are relatively limited in scope and number (Marshall, 2017). According to a recent comprehensive analysis, Montessori education demonstrates favourable outcomes in both academic and non-academic domains (Randolph et al., 2023). This section will present an analysis of the intersection at which Montessori education and neuroscience converge.

a. Importance of movement and cognitive development

In conventional schools, teachers often cite students' restlessness, their inability to 'sit still' for extended periods, and their constant need to move around (A. Larrison in Lyman, 2016). Montessori recognises the importance of movement in learning and provides opportunities for physical activity in the classroom. For her, movement is a factor of intellectual growth (Montessori, 1966).

> *Experience and activity are necessary, in order to make intelligence expand and acquire greater understanding (Montessori, 1956).*

This is a vital idea that has also been confirmed by neuroscience. Research has shown that there is a correlation between physical movement and cognitive processes, which suggests that movement can improve learning, memory, brain plasticity and grey matter volume, as well as mood (Fabri & Fortuna, 2020). Embodied cognition involves the convergence of the physical body and mental processes, which appears to enhance and enrich comprehension (Larrison in Lyman, 2016). Much of the existing research has been conducted in the domains of maths, chemistry and science, however, some programmes have been developed to support the analysis that even reading ability could be enhanced (Larrison in Lyman, 2016).

Based on Rogers and Thomas' recently published work (2023), 80% of the brain's neurons are responsible for movement coordination.

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The corpus callosum is a thick bundle of nerve fibres situated in the brain that links the left and right cerebral hemispheres. This structure facilitates inter-hemispheric communication, in which each hemisphere processes information from the opposite side of the body. As such, the left side of the brain handles data from the right side of the body. The corpus callosum amalgamates these inputs to create a comprehensive understanding (Larrison in Lyman, 2016)

In her book 'The Absorbent Mind', Maria Montessori discussed the role of the cerebellum, a crucial part at the back of the brain, and its contribution to the development of movement in the initial years of life (Montessori, 1949).

One of the most important practical aspects of our method has been to make the training of the muscles enter into the very life of the children so that it is intimately connected with their daily activities. Education in movement is thus fully incorporated into the education of the child's personality (Montessori, 1912, p. 81).

b. Emotional development

Montessori education emphasises the development of emotional intelligence and empathy. Mixed-age environments enable students to form groups and collaborate with peers of varying abilities. Social interactions are therefore ubiquitous and as a result, so is the expression and management of emotions. Socioemotional skills are essential for personal development, social integration and overall well-being. Studies have also shown a better sense of well-being among schoolchildren between 3 and 6 years old who attend Montessori schools versus students from conventional schools (Denervaud et al., 2019).

Neuroscience has shown that emotional experiences have a profound impact on brain development and can shape lifelong emotional responses and social behaviours. The close relationship between emotions and thoughts is associated with learning (Immordino-Yang, 2011). For instance, emotions can significantly impact attention and focus. When a learner is emotionally engaged or invested in a topic, they are more likely to pay attention and process information more deeply. These insights from neuroscience could significantly impact the way we approach and set up learning environments.

Anxiety is a typical stress reaction – a common human sentiment triggered by diverse situations. In fact, it can even have a positive influence on learning and performance (Rogers & Thomas, 2023). Nevertheless, if anxiety becomes overwhelming, enduring and disrupts one's daily routine, it can evolve into an anxiety disorder, which can adversely affect learning and erode self-confidence. (Hartrich in Lyman, 2016).

An important component of Montessori education that can increase or aid children's well-being is the 'guide/teacher'. The teacher's role is to connect children to the environment when they are ready (Randolph et al., 2023). Another element is to let the child act without constantly restraining or intervening (Montessori, 2020). According to Montessori, children learn through first-hand experiences and should be given the opportunity to encounter situations that are not always pleasant. This helps them to develop the skills to navigate and optimise such circumstances (Montessori, 2020).

Interest and motivation play a vital role in the learning process and are highly valued in the Montessori educational setting. The ability to engage in activities that align with one's personal interests can result in broader positive effects beyond academic achievements, which include enhanced well-being and positive emotions (Lillard, 2008; Randolph et al., 2023).

c. Social learning, brain diversity and the prepared environment

Drawing from the Montessori methodology, the Montessori environment functions as a meticulously arranged one that fosters exploration and the joy of discovery, while also facilitating social interactions (Montessori, 1949). The Montessori education is based on the triad of 'environment', 'guide/teacher' and 'child'. (Lillard & McHugh, 2019)

> *When we speak of "environment" we include the sum total of objects which a child can freely choose and use as he pleases, that is to say, according to his needs and tendencies. A teacher simply assists him at the beginning to get his bearings among so many different things and teaches him the precise use of each of them, that is to say, she introduces him to the ordered and active life of the environment. But then she leaves him free in the choice and execution of his work (Montessori, 1912, p. 65).*

A key emphasis lies in nurturing social relationships, a cornerstone that empowers children not only to be enthusiastic learners but also individuals who can establish personal objectives within a communal context. This social growth is facilitated through the observation of peers and the emulation of specific behaviours (Schmelzeisen, 2023). Social learning unfolds indirectly, which leads to efficiency gains. These shared encounters also contribute to shaping children's recollections. Consequently, the development of comparable neural formations might not hinge solely on exchanging experiences and belief systems, but might also be achieved through the mere process of learning through observation and imitation (Montessori, 2020). Neuroscience highlights the significance of the environment in shaping brain

development. A stimulating, enriched environment with diverse learning materials can positively influence neural connections and cognitive development in children. Studies on animals as mentioned in Bruer (1997) present the idea that an environment that is rich and varied in a relational and physical sense affects the brain (Bruer, 1997; Di Garbo et al., 2011). One of the Montessorian insights is that the locus of learning can happen in the prepared environment and as the child grows up within the local community.

In the Montessori classroom, a diverse assembly of students coalesces. Typically, these students span a three-year age range, such as 0–3, 3–6, 6–9, 9-12 and even 6–12 years old. This composition strategically fosters the establishment of social bonds and learning connections among children of varying ages (Montessori, 1949). The prepared environment is structured so that it can enable the child's free activity (Montessori, 2020). Through interaction within this environment, children attain concentration and knowledge, as well as self-defence (Montessori, 2020).

Since every individual's brain possesses distinct attributes, the process of learning cannot occur simultaneously or via identical methods. Given that a class comprises a diverse group of students, each of whom exhibits individual traits and learning modalities, the Montessori setting and methodology empower each student to advance according to their personal rhythm. Moreover, since children of a certain age exhibit similar needs, irrespective of their cultural background, Montessori learning environments remain consistent worldwide (Randolph et al., 2023).

> *It has been our experience that if the child and the adolescent do not have a chance to engage in a true social life, they do not develop a sense of discipline and morality (Montessori, 2018a, p. 28).*

d. The way to the abstract through the concrete

> *The hands are the instruments of man's intelligence (Montessori, 1949, p. 23)*

Montessori schooling promotes active, hands-on learning (Lillard, 2008; Randolph et al., 2023). Findings from cognitive science suggest that engaging with the physical environment is essential for brain development. The utilisation of manipulative materials, particularly prevalent in early childhood education, has the potential to activate various sensory pathways in the brain, which leads to more profound learning experiences (Laski et al., 2015). Manipulatives are materials used to teach a specific concept in a concrete form. They help children understand abstract ideas. However, it is worth noting that viewpoints vary, with some studies indicating that manipulatives

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can enhance perception and thinking but not understanding (Ball, 1992). Despite being tangible objects, comprehending how manipulatives symbolise concepts necessitates a form of abstract thinking (Laski et al., 2015).

The Montessori materials, however, align with the four principles that enhance the efficacy of manipulatives based on Laski (2015), which include:

- Prolonged and repetitive utilisation of a manipulative over an extended duration to solidify understanding. When neurons are activated repeatedly, the connections between them strengthen, which leads to more robust learning and reduced forgetfulness (Masson, 2020). Nonetheless, excessive repetition of a particular concept that requires minimal effort could result in boredom (Masson, 2020). In the Montessori approach, repetition is regarded as a crucial element of learning that enables children to achieve mastery of specific skills. After carefully observing children and taking their ages into account, Montessori recognised the significance of repetition in certain activities as a way for them to practise and attain self-perfection. As the students grow, the process of repetition also undergoes a logical evolution. Repetition is appealing when there is an element of differentiation involved.
- Each material facilitated the child's engagement with a single concept, which eliminates distracting elements and enables the child to concentrate on one notion at a time.
- Certain Montessori materials, in particular in the area of mathematics, are used to support the execution of mathematical procedures. These materials start as concrete representations and progressively evolve into more abstract forms, which grants learners the opportunity to bridge the gap between tangible experiences and conceptual understanding. This transitional process allows students to grasp complex ideas by initially interacting with manipulatives that they can touch, move and control. As they become more comfortable with these foundational concepts, learners can then extend their comprehension to encompass more theoretical and abstract notions. This pedagogical approach nurtures a deeper grasp of the subject matter, which enables students to cultivate critical thinking skills and transfer their knowledge to diverse contexts. This idea is known as 'concreteness fading' (Fyfe et al., 2014).
- The Montessori materials are introduced by the guide/teacher, not only verbally but also by physically demonstrating their manipulation. In the case of children under six years old, verbal language is

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intentionally omitted, which allows children to direct their attention towards the gestures demonstrated by the guide/teacher. Conversely, with the older students, alongside describing the materials, the guide/teacher explains the link between the material and the underlying concept it symbolises.

e. Self-regulation, executive functions and autonomy

Montessori education places significant emphasis on order, concentration and self-regulation skills, which align with the development of the brain's executive functions. These functions, associated with specific brain regions, are crucial for academic and social success as well as mental and physical well-being (Diamond, 2012). They play a critical role in higher-order thinking and decision-making. Neuroscience research supports the idea that such skills can be cultivated and refined through practise and appropriate learning experiences (Lillard, 2013; Zelazo & Carlson, 2012).

The child who has never learned to work by himself, to set goals for his own acts, or to be the master of his own force of will is recognizable in the adult who lets others guide his will and feels a constant need for approval of others (Montessori, 2018a, p. 16)

Montessori highlights the child's ability to work independently, set goals and wield their willpower. The absence of these aspects becomes evident in adulthood in those who rely on external guidance and seek constant approval. Students who are in charge of their own learning lay the foundation for becoming lifelong learners. Furthermore, the freedom to manage their time in an unstructured way contributes to the growth of independence, self-regulation and problem-solving skills (Franco & Robson, 2023).

A noteworthy research project conducted in Switzerland and published in 2019 explored creativity and executive functions among students in both Montessori and conventional schools. The findings revealed that while creativity levels were similar among students from the different schools, 'working memory' proficiency exhibited a minor disparity, with Montessori students outperforming their counterparts from conventional settings (Denervaud et al., 2019). It is important to acknowledge, however, that the socio-economic status of students' families can influence these traits.

Working memory holds implications for self-regulation, a term introduced in the 1980s to describe the interplay between an individual, their environment and specific behaviours (Berger, 2023). Self-regulation is trainable, and practices such as role-modelling by teachers, coaching with strategic utilisation and internalisation of strategies contribute to

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its development. This leads to enhanced self-regulation and eventually independence.

Free choice is one of the highest of all the mental processes (Montessori, 1949, p. 246)

f. Sensitive periods

Montessori observed that children go through 'sensitive periods' during infancy, during which they are particularly receptive to learning specific skills and concepts (Montessori, 1966). She believed that understanding these innate sensitivities could provide profound insights into a child's mental growth.

The child learns to adjust himself and make acquisitions in his sensitive periods. These are like a beam that lights interiorly or a battery that furnishes energy. It is this sensibility which enables a child to come into contact with the external world in a particularly intense manner. At such a time everything is easy; all is life and enthusiasm. Every effort marks an increase in power. Only when the goal has been obtained does fatigue and the weight of indifference come on (Montessori, 1966, p. 40).

This concept aligns closely with modern neuroscience research, which supports the idea that the brain undergoes critical periods of development in which specific neural connections are strengthened based on a child's experiences (Singer in Battro et al., 2008; Fabri & Fortuna, 2020).

Montessori's pedagogical approach places a significant emphasis on providing appropriate learning opportunities during these sensitive periods. Her philosophy is rooted in the understanding of brain plasticity, in that the brain's ability to adapt and reorganise itself is at its peak during these critical periods. Bruer, in his research, highlights the importance of addressing any impairments in a child's senses during these critical periods to enable their smooth development (Bruer, 1997).

One of the remarkable observations Montessori made was children's exceptional sensitivity to language acquisition. She noted that a child's ability to absorb language is so profound that they can acquire foreign languages effortlessly during their early years, particularly from birth to 3 years old.

A child can only acquire the words he hears spoken around him. This is not teaching but absorption. The child is, by nature, hungry for words; he loves strange, long words like the names of dinosaurs and constellations.

He takes in all these words without understanding their meaning, as his mind is still taking language in by a process of unconscious absorption *(The 1946 London Lectures, 2018, p. 148).*

In the realm of neuroscience, these sensitive periods are also referred to as 'critical periods' and are considered a property of neural

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circuits. The impact of these critical periods is reflected in a child's behaviour and their capacity to acquire essential skills and knowledge (Singer in Battro et al., 2008; Knudsen, 2004). According to findings in neuroscience, once these critical developmental periods conclude, neurons cease their ability to form new connections, and the existing connections become fixed and can no longer be eliminated (Singer in Battro et al., 2008).

In summary, Montessori's pioneering insights into sensitive periods in child development have found resonance in contemporary neuroscience. The concept of critical periods, in which the brain is most adaptable to learning, underscores the importance of providing enriching experiences and addressing any challenges during these formative years, which ultimately shape a child's cognitive and behavioural development.

> *For these mites of four, once was enough, though a child of seven requires much repetition before he grasps the word correctly. All this was due to that special period of sensitivity; the mind was like soft wax, susceptible at this age to impressions which could not be taken in at a later stage, when this special malleability would have disappeared (Montessori, 2018b, p. 5).*

g. Memory

The capacity for learning in children is truly remarkable, even though they lack fully developed memory as we understand it. Montessori, in her book 'The Absorbent Mind' (1949), points out that while we often say, 'the child remembers things', it is important to recognise that children do not possess a mature memory system from the start. Instead, they actively construct their memory. Memory, in fact, is a complex and dynamic process that involves the entire brain. Two key brain regions play pivotal roles in memory formation: the hippocampus and the neocortex. The hippocampus plays a role in learning, in which new information is initially stored. As children learn and experience new things, the hippocampus acts as a temporary storage space.

However, the real magic happens in the neocortex. Memories stored in the hippocampus have the potential to transform into long-term memories as they are further developed and integrated into the neocortex. This process is crucial for learning and understanding, and it often takes place during the initial hours of sleep. Interestingly, this process can be influenced by external factors. For instance, threats and negative emotions, as noted by Rogers and Thomas (2023), can impact the coding of information and thus affect memory processing. Therefore, creating an environment that is positive and conducive to learning is essential for memory consolidation and learning success.

In the realm of education, Montessori's approach, as explained in her work from 2020, emphasises the importance of providing a plethora of materials to students. This diverse range of materials allows children to explore and work on the same concept repeatedly, enabling them to maintain their interest until they fully grasp the concept. By doing so, educators can harness the remarkable learning capabilities of children, even as they actively construct their memories.

4. CONCLUSION

As previously stated, the exploration of links between educational approaches such as Montessori and brain functioning is constrained by limitations in research (Ansari, 2005). Numerous challenges hinder the execution of high-quality educational studies, including investigations into the Montessori methodology (Marshall, 2017). Furthermore, the absence of trademark protection for the term 'Montessori' has led to a wide range of differing interpretations (Randolph et al., 2023).

While there is increasing evidence to support the alignment of Montessori principles with neuroscientific findings, it is imperative to acknowledge that neuroscience is a dynamic and continually evolving field. The connections between the Montessori method and neurosciences remain a topic of ongoing research, discussion and debate. Further studies may provide additional insight into how Montessori principles align with our evolving understanding of the developing brain.

Through our exploration of the convergences between Montessori's educational principles and neuroscience, we have aimed to shed light on how the philosophy and practices pioneered by Maria Montessori were remarkably forward-thinking, preceding even the advent of advanced neuroscientific research. This alignment underscores the enduring relevance of her methods, which continue to serve as a powerful force in promoting effective and holistic education. As we move forward, the synergy between Montessori and neuroscience presents an exciting opportunity to shape the future of education, which fosters a more comprehensive and impactful approach to nurturing young minds.

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