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SEE BEYOND BEHAVIORAL COMPARISONS: NEUROSCIENTIFIC PERSPECTIVES ON THE MONTESSORI PEDAGOGY

Mathilde Gaujard & Solange Denervaud

Abstract: Education is key to fostering the adaptive skills needed to face today's challenges. However, Western-like traditional pedagogy is limited in promoting such skills, so a drastic reform is crucially needed. Recently, the Montessori pedagogy has aroused scientific interest. Behavioral comparative studies between traditionally and Montessori-schooled children confirm benefits at several levels for schoolchildren, especially in self-monitoring and creativity abilities. Despite these facts, large-scale implementation of this pedagogy is limited in public schools. Maybe those behavioral comparisons, by providing binary outcomes (i.e., better versus worse), limit the broader transfer of this pedagogy as it refrains from grasping the *how* and *why* it works. Accordingly, neuroimaging studies may complement positively this limitation and provide a deeper understanding of the neurodevelopment that the Montessori pedagogy supports and trains. Here we review behavioral studies and recent neuroscientific work, a perspective that explains most of the benefits observed and may help knowledge transfer to practice.
Keywords: Montessori pedagogy, traditional pedagogy, scholastic outcomes, brain-behavior.

Introduction

In June 2022, UNESCO's International Commission on the Futures of Education declared: "Education is our best tool to optimize the relation between democracy, diversity, and justice". We are currently experiencing environmental, political, and social instabilities; drastic and ambitious changes must be made to face these challenges. Despite more than half a century of national and international efforts in education and development, promises of quality education for all remain unfulfilled (Declaration of the International Commission on the Futures of Education, UNESCO, June 2022). To implement long-lasting changes in education, we must re-evaluate its essence, in an evidence-based manner.

Scientific efforts in this direction have been carried out for several years, reflected in the emergence of interventional programs: brief, highly targeted programs aimed at training intensively specific cognitive skills (e.g., executive functions, working memory; Traverso et al., 2015; Studer-Luethi et al., 2022). However, the effectiveness and generalization of the benefits of these "laboratory-to-classroom" interventions are minor and not persistent (Melby-Lervåg et al., 2016; Kassai et al., 2019). Therefore, it is necessary to adopt a new scientific perspective freely inspired by reverse engineering approaches; "from the classrooms to the labs" to make deeper changes. UNESCO pushes in this direction: "Transforming education means going beyond reforms aimed at improving our educational systems and our educational practices. Rather than leading to improved versions of existing systems, transformation must lead to education systems different from those of today […] A bold transformation of education is therefore urgent" (Declaration of the International Commission on Future of Education, UNESCO, June 2022).

The Montessori pedagogy

Although a century old, the Montessori pedagogy seems timely. Maria Montessori wrote, "Education should no longer be mostly imparting of knowledge, but must take a new path, seeking the release of human potentialities" (Montessori, 1946) The benefits of this alternative pedagogy need to be studied more in-depth to invite a wider audience to be freely inspired by its essence. In Montessori theory, the essential elements of education comprise setting children free in a prepared environment with a specially trained teacher (Lillard & McHugh, 2019). In these schools, students learn through self-determined activities (i.e., children are free to select their work within a panel already introduced by the teacher). Feedback on their work is done without formal assessment (e.g., exam, grade, test). Instead, feedback is done by using didactic materials with self-

corrective information, through interactions with peers, or by the teacher who advises but does not judge. In addition, children's work time is not interrupted for at least three hours. From a social point of view, children generally interact freely with their peers of different ages, mainly for the interest of working together (https://montessori ami.org). To resume, Montessori environments are carefully prepared by the teacher to provide opportunities for children's development while protecting children from obstacles to that development (Lillard & McHugh, 2019). Therefore, even the interaction between space and pedagogy is designed to support learning. The success of this design has raised the interest of designers and architects (Al et al., 2012; İslamoğlu, 2017; Mendoza et al., 2021). Together, these aspects from the learning strategies to the social and physical environments drastically differ from Western-like traditional school pedagogy.

The benefits of Montessori pedagogy on child behavior

The Montessori pedagogy represents the largest educational alternative in the world with a total of 15,763 schools, spread across 154 countries, and approximately 9% are government-funded (Debs et al., 2022). The countries with the highest number of Montessori schools are the United States, China, Thailand, Germany, Canada, and Tanzania. The schools are all based on six pillars which are central in the implementation of the Montessori pedagogy: (1) supporting Montessori philosophy, (2) mixed-age grouping, (3) Montessori-trained teachers, (4) Montessori material, (5) freedom of choice, (6) uninterrupted work block (Debs et al., 2022). This pedagogy, therefore, arouses the curiosity of scientists, and experiments are run to compare Montessori with traditionally schooled children. Overall, benefits for children from Montessori schools appear at the (1) academic, (2) sensory-motor, (3) socio-emotional, and (4) creativity levels.

Academic skills

According to the review by Marshall (2017) and confirmed by the recent meta-analysis by Demangeon et al. (2023), Montessori pedagogy has a high effect on academic achievement. For example, five-year-old children enrolled in Montessori schools perform better in language (letter and word identification, phonological decoding) and math (problem-solving) than peers enrolled in traditional schools (Lillard & Else-Quest, 2006). These findings are replicated in other countries and cultures (Djamaloeddin & Dodd, 2021; Hallumoğlu et al., 2021; Denervaud et al., 2019). In addition, if students are asked to evaluate themselves, they report a higher sense of self-efficacy, especially in reading skills (Setiawan & Ena, 2019). Parents are also more aware of their children's progress (Tympa et al., 2022). Overall, Kayili & Ari (2011) show that the Montessori program better prepares preschoolers for elementary school than the traditional program. This is likely because fundamental cognitive processes, such as executive functions (i.e., cognitive tools for carrying out an intention) and error management, are trained more.

Indeed, when 5-year-olds American children are tested on their cognitive flexibility (i.e., one of the key aspects of executive function), children enrolled in Montessori schools score better on this test than children enrolled in traditional schools (Lillard & Else-Quest, 2006). This is true provided that the Montessori pedagogy is strictly applied (Lillard, 2012; Phillips-Silver & Daza, 2018). However, a Swiss study shows no difference in overall executive functions between kindergarten children experiencing the Montessori pedagogy and those experiencing the traditional pedagogy (Denervaud et al., 2019). Perhaps Swiss traditional schools allow for better development of executive functions than American traditional schools. Or it may be that given the high socioeconomic background of the Swiss children enrolled in the study, they all had access to extracurricular activities, and these also develop executive functions (e.g., martial arts, yoga) (Diamond & Lee, 2011).

Learning from mistakes is also a key learning process; detecting an error means taking the time to realize that something didn't go as planned, while learning implies finding solutions to fix it (i.e., self-correction). The evaluation of 234 children aged 4 to 15, highlights that children in Montessori schools detect

their errors younger than children in traditional schools. Furthermore, teenagers from Montessori schools are more likely to self-correct than teenagers from traditional schools (Denervaud et al. al., 2020c). In addition, for children aged 8-12 in Montessori schools, errors or correct answers are not perceived as "good" or "bad", they are simply facts without judgment (i.e., being right or wrong is just a fact, a piece of information about the on-going process). However, among children aged 8-12 in traditional schools, there is a strong affective reaction linked to the fact of answering correctly as a positivity bias (i.e., 'it is good to be right'). This difference suggests that the experience of grades and rewards/punishments induces an affective value-based judgment bias associated with the learning process (Denervaud et al., 2021b).

The goal of the Montessori pedagogy is not only to develop children's academic knowledge and cognitive skills. It is adapted for the development of the whole child, including sensory-motor, social-emotional and creative levels.

Sensory-motor skills

The Montessori pedagogy is mostly based on a set of didactic materials as learning means. For example, to prepare for reading and writing, sandpaper letters are used. The child runs their finger over a sandpaper letter and pronounces the letter aloud. In this way, proprioception, kinesthesia, visual and auditory systems, as well as motor gestures are co-engaged. This facilitates memory encoding in the body (i.e., embodiment), beyond simple associative learning.

To test the influence of the Montessori pedagogy on fine motor skills, children can be asked to place tiny flags in pre-designed holes. 5-year-olds students in the Montessori group show higher accuracy, speed, and consistent use of the dominant hand on the post-test, eight months later, than students in the traditional group (Bhatia et al., 2015). Their sensorimotor training is also reflected in their multisensory integration (i.e., the ability to use multiple senses together) which is superior to their peers in traditional education (Denervaud et al., 2020b). Training the senses, without being restricted to simple visual and auditory systems, increases students' long-term memory and intelligence. These results confirm that beyond the academic concepts to be learned, the use of Montessori didactic material also promotes the child's sensory-motor abilities and concepts embodiment (i.e., deep integration of knowledge).

Socio-emotional skills

The Montessori pedagogy relies on interactions between peers to promote learning. Classes are made up of different age levels (e.g., children from 3 to 6 years old are mixed in one classroom). In this way, the youngest children are inspired by the older ones, and the older ones consolidate their learning by explaining to the younger ones (Montessori, 1936).

To study the impact of this social factor, social dilemmas are used with 5-year-olds children (e.g., after hearing a story about a child grabbing a swing at another child, the participant is asked how to react to that scene). Equity and justice are used more by students in Montessori schools to solve these problems, compared to students in traditional schools. This position is also found when the children are in real-life situations, like during recess for example (Lillard & Else-Quest, 2006). Prosocial skills emerge from the ability to attribute mental states to others, which can be measured through the theory of mind task (i.e., the child is told a story about different protagonists and is asked questions about the different mental states of the protagonists to see if they can infer complex and abstract knowledge to others). In such a task, 80% of 5-year-old Montessori school children succeed in attributing mental states to others than themselves, traditional school children respond at the level of chance (Lillard & Else-Quest, 2006). Overall, the Montessori pedagogy has a real effect on the acquisition of social skills, as Demangeon et al. (2023) have recently shown by analyzing several studies on the impact of this alternative school environment on child development. Promoting social interactions in school contexts (i.e., peer-to-peer learning), is a means to develop adequate emotion recognition abilities; the

capacity to correctly identify others' emotions and manage one's own. Students in Montessori schools develop a better capacity to understand feelings, regulate emotions, and solve social problems, compared to students in traditional schools (Kayili & Ari, 2016; Dereli İman et al., 2019). Their emotion regulation skills are trained since school starts. Indeed, in Montessori classrooms, there is only one piece of each didactic material available. This is meant to let everyone be free to choose the activity if it is available only, otherwise to wait for it. Thus, the child trains their delay of gratification; learning to wait, to look forward to doing an activity (i.e., attention/impulse self-regulation) (Tiryaki et al., 2021).

The natural development of these skills may be hindered by the competitive environment inherently induced by grades and rewards/punishments habits of traditional schools, given its impacts on students' emotions (e.g., Mella et al., 2021). These practices are not present in Montessori schools. This difference may contribute to the attentional bias that students in Montessori schools develop toward positive emotional stimuli and students in traditional schools develop toward negative emotional stimuli. Furthermore, the latter show greater sensitivity to fear, whereas children from Montessori schools are better at reading and classifying others' emotions (Denervaud et al., 2020d).

The good development of academic, sensory-motor, and socio-emotional skills in a Montessori environment makes provides the ground truth for the development of children's creative potential.

Creative skills

Several studies report higher creative abilities in Montessori than traditionally schooled students, measured with different tasks at different age-range. An example to assess creativity is story writing. When comparing 12-year-olds on such tasks, the Montessori students' essays are found to be more creative and included more sophisticated sentence structures than those of the traditional school students (Lillard & Else-Quest, 2006). Besançon and Lubart (2008) also point to the positive influence of Montessori pedagogy on the development of creativity over a two-year period using verbal and drawing measures. This is confirmed by Fleming et al. (2019), Eon Duval et al. (2022), and Denervaud et al. (2019) who show for example that at kindergarten and elementary age, Montessori school children score higher than children of the same age in traditional schools, on different forms of creative thinking (i.e., assemble concepts in a creative manner, or derive ideas from a given concept). These studies suggest that pedagogies clearly affect higher cognitive functions, including creative thinking.

Creativity also emerges from a good fit between a person's skills in an activity, the readiness to deepen that knowledge and the challenges offered by that activity. This good fit allows experiencing a state of "flow", a perfect match between thoughts and actions. Rathunde speaks of "flow" as momentum when a person is fully focused on a task at hand, relatively oblivious to time, and knowing about what needs to be done from one moment to the next (Rathunde, 2001). In the school context, students following Montessori pedagogy report experiencing a state of "flow" and show higher intrinsic motivation than students following traditional pedagogy (Rathunde & Csikszentmihalyi, 2005).

Together, the above-mentioned studies highlight the benefits of the Montessori pedagogy. However, there are some comparative studies that do not replicate these findings (e.g., Lopata et al., 2005), or depending on the age level or the skills assessed, report diverging results (e.g., Peng & Md-Yunus, 2014; Laski et al., 2016; Snyder et al., 2022). It seems that the quality of implementation of the Montessori pedagogy and the time spent in a Montessori schooling system are two essential factors for the emergence of the benefits of such pedagogy (Basargekar & Lillard, 2021; Lillard, 2012).

Beyond the school period

What about the benefits of this pedagogy beyond the school years? While the Montessori education is certainly most prominent up to the age of 12, it is also offered through high school in some countries (e.g., Denmark). So far, studied have been run on students at the end of elementary years. There, high school students who had experienced the Montessori pedagogy from kindergarten to 11 years old were compared to students who had followed the traditional pedagogy. Results indicate that experience of a Montessori education is associated with higher high school math and science scores (Dohrmann et al., 2007) and better adaptation to higher education expectations. In fact, during this transition from high school to higher education, students who received Montessori education have fewer symptoms of anxiety and depression, greater life satisfaction, and better academic performance than students who received traditional education (Shankland et al., 2010). In addition, what stands out for former Montessori students is the enjoyment of learning: they remember having a greater interest in schoolwork and a sense of community, compared to former students from traditional schools. They also gave less importance to class ranking, punishments, rewards, and standardized tests (Snyder et al., 2023).

Even a few years in a Montessori school brings benefits. Indeed, attending a Montessori school for at least two years of childhood is associated with gains in adulthood, in general well-being, engagement, social confidence, and self-confidence. The longer one has attended Montessori for years, the more well-being one has in adulthood (Lillard et al., 2021).

Support for disadvantaged populations

The socio-economic level of the family plays a major role in supporting the development of a child's academic, social, and emotional skills (e.g., Caro et al., 2009; Van Oort et al., 2011). While this is true, the Montessori pedagogy has the potential to compensate for the shortcomings related to disadvantaged socioeconomic backgrounds. An American study followed 141 children for three years (ages 3 to 6), enrolled in Montessori and traditional public schools, in a very poor city. Results show that disadvantaged children enrolled in Montessori classes develop better academic, social, and executive skills and greater enjoyment of learning. In addition, their academic levels are found equivalent to those of children traditionally educated in privileged settings after two years of Montessori schooling (Lillard et al., 2017). Other results also point in this direction with older students and students from minority populations in the United States (i.e., Black, Hispanic) (Snyder et al., 2022; Ansari & Winsler, 2014; Brown & Lewis, 2017). By adulthood, 92% have an undergraduate degree (compared with less than 40% of Americans in general), and 25% have postgraduate degrees (Lillard et al., 2023). Benefits are also found for disadvantaged populations in France (Courtier et al., 2021). These studies challenge the prevailing misconception that Montessori is an elite pedagogy for predominantly white students in private schools.

Support for atypical developments

A recent American survey indicates that Montessori schools accommodate slightly more students with learning difficulties than traditional schools, for children aged 3 to 6 (Long et al., 2022). As the Montessori pedagogy responds to the individuals' needs, and not to a developmental norm, the learning pace of each child is respected, making it possible to break free from any standard and empower each one's potential. Consequently, improvements in cognition, independence, self-care, and communication in children with intellectual disabilities who experienced the Montessori pedagogy, compared to children who experienced the traditional pedagogy, are observed (Afshan et al., 2022). Similarly, 5- to 6-year-old children with attention deficit hyperactivity disorder (ADHD) improve their attentional skills in a Montessori environment compared to children in a traditional environment. This may be due to the didactic materials that engage their bodies and

senses, to coordinate the eye and hand as well as mobilize their tactile, visual, and auditory senses (Dogru, 2015), concomitant to uninterrupted working time that is less stressful.

In conclusion, thanks to its ability to follow each child's unique rhythm and respond to individual needs, while relying on peer-to-peer learning, the Montessori pedagogy brings benefits to all children and undoubtedly also to teachers (i.e., it may be more rewarding for the teacher to see students' progress and thrive in a Montessori school than to feel students become stressed and competitive in a traditional school).

Understanding Montessori pedagogy

Given the large number of scientific facts attesting to the benefits of the Montessori pedagogy compared to the traditional pedagogy for children's academic outcomes, socio-emotional well-being, and creative abilities, further confirmed with a meta-analysis (Demangeon et al., 2023), it seems surprising that school reform is slow in listening these evidence. In Switzerland and in France, we observe that talking about the Montessori pedagogy for elementary classes is even met with skepticism and negative reactions, despite teachers begging for changes and being open to such practices. As researchers, we ask ourselves *why*? While we wish for the best for our children, *why* are we not ready to change our habits and question our views? We believe that part of the problem is our mindset. Indeed, adults' history is mostly made of traditional education. Therefore, we have cognitive and emotional biases related to our own schooling experience: we are seeking rapid solutions, as we were less trained to think about problems quietly and hand in hand together for long-term strategies. We are afraid of change and real innovation, as our creativity may have not been sufficiently nurtured and embraced while we were children. We show a tendency to judge ourselves first, but others as well, seen as competitors and not possible partners. Furthermore, we have been told to be brave and endure sorrows, instead of refusing the inadmissible and standing up for values. The first step may be to recognize and understand our own past. However, it may not be enough to get rid of these prejudices, take risks, and live the experience of change. We need to grow a culture of education, based on a deeper comprehension of human development.

Consequently, science should explore pedagogy beyond comparative studies that only report binary outcomes (i.e., 'better/worse than') to focus on the underlying reasons that allow benefits to emerge. In this way, we will move away from dogmatism and cultivate reflection rather than judgment. We believe that the coming years will offer this opportunity to education, for example, by studying children within their school environment (rather than a hierarchical approach from the laboratories to the classrooms) to deduce developmental ground truths. Recently, efforts in this direction have emerged thanks to neuroscience technics. This discipline allows us to abandon the question "Is it better or worse?" and focus instead on the question "How and why does it work? ". We present below the first results allowing us to understand the fundamental mechanisms on which the Montessori pedagogy acts, or any other approach that respects these underlying mechanisms of child development.

What the neurosciences say about Montessori pedagogy

The above-mentioned behavioral studies report differences as a function of school experience, in the processes of *learning how to learn*, such as error monitoring. Strategies trained at school are mirrored in the child's behavior: remembering correct answers or correct errors to find out the solutions. The underlying brain mechanisms of error versus correct response strategies are investigated using functional magnetic resonance imaging technics (*f*MRI) (Denervaud et al., 2020a). Students from Montessori schools have overall higher brain activity than students from traditional schools, suggesting a more active engagement in the proposed mathematical task during the *f*MRI scan. In addition, the connections (i.e., associations) made at the neural level between brain regions differ. Students from Montessori schools simultaneously activate regions of the brain involved in error detection (i.e., the anterior cingulate cortex) and regions involved in problem-solving,

after making an error. This suggests a process-oriented strategy that addresses errors to learn. Conversely, students from traditional co-activated memory-related brain regions (i.e., the right hippocampus) after answering correctly. This suggests an outcome-oriented strategy, learning by heart. The learning strategies promoted by the pedagogical practices are reflected even in the brain connections.

To learn by heart or to understand, these differences are also found in the anatomy of the brain, particularly at the level of the parahippocampus. The main function of this brain region is to associate contextual elements with new information. The results show that the parahippocampus develops more on the side of the left cerebral hemisphere for students from Montessori schools and more on the right side for students from traditional schools (Schetter et al., *In Revision*). This asymmetry reflects the importance given to the episodic context in traditional pedagogy, which favors learning limited to a specific situation. However, in the Montessori pedagogy, it is the semantic context side that is more develops. This form of associative memory allows transferring of knowledge to new situations. This study corroborates other findings that highlight a more flexible organization of semantic memory composed of networks in children enrolled in Montessori classes, with concepts more interconnected and enriched, than in children enrolled in traditional classes (Denervaud et al., 2021a). This seems consistent with differences observed in the learning environments. In traditional pedagogy, students learn concepts in a disjointed way, therefore it is more difficult to establish the relation between concepts and learning becomes a considerable succession of unrelated information to be retained. In contrast, in the Montessori pedagogy, the manipulation of sensory learning materials allows students to perceive abstract concepts through a 3D representation, which facilitates access to the meaning of information. In addition, through peer-to-peer learning, children must rephrase what they have learned to explain it to others, which encourages them to clarify their knowledge and not learn it by heart. Also, children hear about one concept from many other children, so different definitions and examples are used and memorized (i.e., not only the adult's definition). In this way, knowledge is integrated to be transferable to other and more abstract concepts or to other moments of life.

The ability to address errors and adjust behavior accordingly (i.e., self-correct), as well as the habit of memorizing new concepts in a flexible way is also reflected in the quality of brain network activity. If adaptability is not trained enough, communication between brain networks is less fluid. Indeed, in children attending traditional schools, the brain regions responsible for coordinating other brain networks (i.e., the salience network) are more intra-connected, compared to children attending Montessori schools. As a result, the salience network freezes the natural flow of communication between the numerous other brain networks, preventing their proper coordination. Furthermore, children attending traditional schools spend more time in an introspective state (i.e., high activity within the default mode network) than Montessori children. It is a state of idea generation without putting them into action. Taken together, these findings suggest a less flexible thinking mode for children educated in traditional schools (Eon Duval et al., 2023).

School experience modulates neural functional connectivity (i.e., co-activation of brain regions), morphometry (i.e., anatomy of brain structures), and brain network dynamics from a temporal and spatial perspective (i.e., which regions activate at which times). Indeed, participants enrolled in a Montessori school present patterns of brain dynamics closer to the ones of adults (i.e., more brain regions coordinate to work together to achieve a goal) compared to their peers in traditional schools. Indeed, students in Montessori schools show more consistent brain activity over time, particularly in the ventral attentional network called upon for automatic capture (e.g., a sudden noise draws attention and causes the head to turn) and in the dorsal attentional network activated for voluntary capture (e.g., focusing on a conversation), compared to students in traditional schools (Zanchi et al., *submitted*). This suggests that the Montessori school experience allows for a better maturation of brain network dynamics (i.e., network coordination). This could be explained by the mobilization of attention which is different according to the pedagogy: a mainly voluntary control in the traditional pedagogy versus flexibility between voluntary and automatic processes in the Montessori

pedagogy. Knowing the importance of attention for the good progress of learning, it would be interesting to observe in greater depth the modulation of the school experience on the development of attentional networks.

A neuroscientific approach allows us to understand how and why the Montessori pedagogy favors a child's development. However, which features of the Montessori practices are important is not clear yet. Peer-to-peer learning seems to be of particular importance. Indeed, children learn more from interactions with other children than from interactions with adults (Décaillet et al., *submitted*). An enriched and diverse school environment also impacts the development of brain regions involved in social skills (e.g., empathy, the ability to recognize emotions, and communication). Getting to know someone and maintaining social bonds require the coordination of many social skills, and these elaborated logistics are shaped over the school years by social experiences. As a result, children in Montessori schools, compared to children in traditional schools, show greater development of the brain region associated with the construction of self-perception (i.e., the precuneus). But even more disturbing, differences between girls and boys appear in traditionally schooled children. Indeed, overall lower development of the social brain network is observed in boys compared to girls. Whereas for students enrolled in Montessori schools, boys and girls develop brain regions associated with social skills similarly (Grasset et al. *in prep*). This suggests that pedagogical practices play a role in the construction of stereotypes against which today's society is undermined. This gender effect is also found when looking at brain markers of stress (i.e., volumes of the hippocampus, amygdala, and medial prefrontal cortex). Girls in traditional schools show a loss of volume in these brain regions related to stress markers across age compared to their male peers, whereas girls in Montessori schools show a gain in these same brain structures. In general, children enrolled in traditional pedagogy present a slower growth of their hippocampus compared to students enrolled in the Montessori pedagogy (Schwery et al., *Under Review*). These results suggest a latent and repeated stress perceived by students following a traditional pedagogy. The school environment seems to have a major impact on gender inequalities, via the abnormally normalized and standardized social composition of classes, but also via the stressful rhythm of learning.

In conclusion, we review different studies comparing traditional pedagogy with Montessori pedagogy. As highlighted by a recent meta-analysis (e.g., Demangeon et al., 2023), there are benefits for children experiencing the Montessori pedagogy in academic, sensory-motor, socio-emotional, and creative skills, with long-lasting effects. Such pedagogy also counteracts disadvantaged families' socioeconomic backgrounds as well as atypical development or learning problems. Yet these facts do not seem sufficient to induce a reform of current pedagogical practices, especially for the elementary years. It seems important, therefore, to move beyond the desire to prove that some pedagogies are "better or worse", and to enter an era of inquiry and curiosity about "why and how" they work or not. Recent neuroscientific studies on Montessori and traditional pedagogy have shed light on the underlying brain mechanisms that seem nurtured in Montessori pedagogy. It shows that there is a sensitive period for learning about error management, how to train memory processes, how and why creativity skills develop at school, and attention-related forms and processes. These studies further report the need for a socially diverse and stress-free learning environment, especially between the ages of 6 and 12. Pedagogy has an impact on the quality of brain network coordination, as well as on the emergence or not of gender differences.

Scientists will never be able to deliver recipes to teachers. We trust teachers are the ones with precious practical knowledge and understanding. So, scientists should refrain from telling teachers about how to do their job better, and wisely keep the curiosity of understanding human development and widely share new knowledge in a clear and simple way. We are also convinced that to improve the educational system, it is first the adults who must become aware of their own functioning. To do this, it is necessary to give more keys to understanding the biological development of each human being, and the changes will come naturally. In line with UNESCO's comments, we hope that other teams will grasp the relevance of this field of study and

contribute to new knowledge on this topic. "A broad social mobilization to transform education must be able to rely on innovation and research. Education must become a global responsibility, international cooperation must be expanded and made more equitable in a spirit of solidarity that builds trust at all levels." (Declaration of the International Commission on the Future of Education, UNESCO, June 2022).

Competing interests

The authors declare no competing interests.

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