湖南大学学报（自然科学版）
Journal of Hunan University (Natural Sciences)

第 50 卷 第 2 期
2 0 2 3 年 2 月

Available online at http://jonuns.com/index.php/journal/index

Vol. 50 No. 2
February 2023

Open Access Article https://doi.org/10.55463/issn.1674-2974.50.2.29

Experimentation Using Neuropedagogical Methods

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Received: December 24, 2022 ▪ Review: January 20, 2023 ▪ Accepted: February 21, 2023 ▪ Published: February 27, 2023

Abstract: Several studies intend to build bridges between neurosciences, psychology, and education. This study aims to explore the post-learning changes in three methods based on neuroscientific data. By comparing the pre-test and the post-test, this study measured variations of neuropedagogical parameters such as attention, the number of keywords memorized, and active engagement. The results of this study conducted in three high schools in Morocco indicated that students' performance improved significantly between the pre-test and the test station; the psycho-pedagogical parameters measured recorded average scores ranging from 9.24% to 706.25%, and therefore, the use of neuropedagogical principles effectively improves classroom learning. We did not find statistically significant differences between sexes in these psychological and pedagogical parameters.

Keywords: contextualization, memory, learning, neuropedagogical method.

使用神經教育學方法進行實驗

摘要：一些研究打算在神經科學、心理學和教育之間架起橋樑。本研究旨在基於神經科學數據探索三種方法的學習後變化。通過比較前測和後測，本研究測量了注意力、記憶的關鍵詞數量和積極參與等神經教育學參數的變化。這項在摩洛哥三所高中進行的研究結果表明，學生的成績在預考和考試站之間有了顯著提高；心理教育學參數測量記錄的平均分數從9.24%到706.25%不等，因此，神經教育學原理的使用有效地改善了課堂學習。在這些心理和教學參數方面，我們沒有發現性別之間存在統計學上的顯著差異。

关键词：情境化、记忆、学习、神经教育方法。

1. Introduction

Over the past decades, several government initiatives, academic organizations, conferences, and others have emerged to bridge the gap between neuroscience research and education. Much work remains to understand the link between brain behavior and children's learning and to translate the laboratory research results to classroom learning situations. Education has always been based on behavioral paradigms, reflecting the contribution of cognitive psychology. We now know that the processes when a child properly develops until twelve years old relate to different mental tasks in the human brain. Several teams have worked in the laboratory to explain the learning mechanisms of our brain, notably [1], which recorded neurons selective to fragments of objects, some of which already have the approximate shape of letters. With exposure to writing, these networks could thus reorganize or "recycle" themselves to form a hierarchical pyramid of increasing invariance, capable of recognizing first letters, then their assemblies into graphemes and morphemes, and finally words or their fragments [2].

The systems needed to perform seriation, transitivity, classification, etc., are different neural circuits in the brain (even if they overlap), so they present individual problems for students as they develop [3]. Modern research on learning processes inevitably links education and neuroscience; it, therefore, seems appropriate to consider how we might apply our increasing understanding of brain development and functioning to explore educational issues [4].

To help teachers overcome the dilemma they face, the real challenge is to translate laboratory results into strategies to improve learning, although linking research and practice is not always evident [5]. One of the crucial mechanisms to address these challenges will be the development of interdisciplinary training programs in which, on one hand, neuroscientists master educational research and pedagogy, and, on the other hand, educators and educational researchers are exposed to the latest neuroscientific discoveries, theories, and methods, including their limits. There should be bi-directional and reciprocal interactions between the two disciplines of neuroscience and education; moreover, the research derived from each of these fields is considered compelling in its right [6].

2. Materials and Methods

2.1. Characteristics of the Sample

The study involved a total of 91 students (aged 12 to 18 years) divided into eight classes and three subjects in three secondary schools (“Moulay Idriss” high school, “Fechtali” high school, and “Alandalouss” middle school) in Casablanca with the collaboration of three school principals, and three high and middle school teachers (one female and two male). They all gave their consent to collaborate in this experimentation. Their ages varied from 25 to 57 years old, and their experience was at least six years.

The students were reassured, informed, and prepared to behave as naturally as possible with a stranger in their classroom. Before starting the experimentation of our system, we held several interviews: starting with an exploratory interview with each principal of the partaking schools to prepare the experimentation field that allowed us to define the list of teachers who were willing to participate in this experiment. Following this first encounter, we organized short training sessions with the teachers around the following axes: the interest in the study and the contribution of cognitive neurosciences for pedagogy, the principles of learning based on neurosciences, and the experiments carried out internationally.

Later, it was mandatory to define, with each teacher separately, the approach for the proposal of the theoretical sheets and constructing the practical pedagogical sheets and the didactical tools necessary for each lesson. On the other hand, we also defined the sequences that will apply as practices with the control group and arranged two teaching sessions per neuropedagogical method, each with two pre and post-test evaluations. This study goth the approval of the educational inspectors and the provincial director of Ben M'sick-Sidi Oth.

2.2. Neuropedgogical Methods

The tool used in this study was a design of three Neuropedagogical methods inspired by some works [7, 5, 8, and 9] whose aim is to test whether neuroscience research is capable of changing teaching practices to make them more effective and whether it can help learners take full advantage of their intellectual and emotional capacities.

The methods were adapted to our situation and then implemented in the experimental classes while considering the dimensions of the socio-demographic characteristics of the schools. For each method, we specified the roles of the teacher and student during the experimentation session (in the form of a sheet).

The experimental hypothesis has the following content:

- Subject(s) of application
- Samples:
  - Class level (x),
  - Total number of employees (G. Exp): Number, Male, Female;
- Description of the method to be tested:
  - Describe what the teacher should do in this experiment,
  - What the student must do in this experimentation;
- Student Assessment:
  - Number of questions,
  - Structure and nature of the questions.

Table 1 shows the description of neuropedagogical methods.

Table 1 Description of neuropedagogical methods (Developed by the authors)

Hypothesis of the method	Pedagogical activities	Roles of the teacher and/or student
Consolidate learning by developing semantic memory.	1. "Contextualization of learning"	Start from the learner's experiences and authentic situations to present a situation that makes sense to them.
Consolidate learning through memorization	2. "Memory cards"	At the beginning of the session, each learner chooses one of them to answer. The student who answers correctly will get a bonus, the one who does not gives his hand to a classmate who must save him and share his bonus with him. The process is repeated in this way to reach all the students in the class and all the learning concepts
Facilitate understanding and develop a memorization strategy	3. "focused on the essentials"	Prioritize the essential concepts. On a handout was distributed to students to note the essential concept being studied. Propose instructions asking for the writing of a given subject according to a Canvas table

2.3. Instrument

The data were collected through guided observations using a grid to apprehend the behavior of the learners in class during the pre-test and the experimental session as a post-test according to the suggested pedagogical sheets.

Evaluation grids duly completed and reviewed with the teacher in pre-test and post-test were used to measure the following variables.

Table 2 Evaluation grid of the experiments conducted (Developed by the authors)

General information	Technical information	Variables measured in pre-tests and in post-tests
Gender Level	Theory and practical experience	Attention Active engagement Error correction Number of key words memorized

Direct observations measured variables such as attention and active engagement are by in class during learning activities according to a Likert scale in post-test and pre-test, while the other variables, in this case, the number of memorized keywords, whether the mistake was corrected or not, and a written test measured the grades at the end of the experimental session and in two periods, post-test and pre-test.

2.4. Data Analysis Process

The information collected was processed using SPSS (Statistical Package for the Social Sciences, Version 25). For quantitative data, we used the Wilcoxon test, a non-parametric alternative to the t-test for paired samples (pre-test and post-test). This allowed us to test our hypothesis that neuroeducation can help learners develop a more alert brain and enable them to be more active, attentive, motivated, and significantly more able to overcome difficulties. This hypothesis is verified by checking whether the psychoeducational parameters vary considerably between the pre-test and post-test of the experiment. The significance level was $p < 0.05$.

3. Results

Tables 3 and 4 do not show statistically significant variation in psychoeducational 157 parameters between sexes; however, they vary for the six neuroeducational 158 methods between the groups in pre-test and post-test according to the following order: 159 highly significant *** ($p < 0.001$), moderately significant ** ($p <0.01$) insignificant *($p < 0.05$), and non-significant ($p \geq 0.05$).

Table 3 Effect of teaching approaches on variations in the means of psychoeducational parameters (Developed by the authors)

Neuropedagogical methods	Period	Attention	Active engagement	Number of memorized	Period	Attention	Active engagement
Contextualization of learning (N = 27)	Pre-test	1.37 ± .56	1.48 ± .64	10.11 ± 2.38	1.19 ± .79	1.52 ± .51	7.04 ± 6.62
	Post-test	2 ± 00	2 ± 00	13.74 ± 1.75	1.30 ± .47	2.00 ± .0	12.04 ± 8.04
Memory cards (N = 38)	Pre-test	1.05 ± .23	1.34 ± .48	8.92 ± 2.79	.16 ± .44	1.00 ± .33	10.55 ± 1.69
	Post-test	1.50 ± .51	1.84 ± .37	12.39 ± 2.20	1.29 ± .80	1.84 ± .37	13.57 ± 1.79
Focused on the essentials (N = 26)	Pre-test	1.42 ± .76	1.19 ± .69	13.81 ± 2.50	1.46 ± .71	1.54 ± .65	14.19 ± 2.28
	Post-test	1.69 ± .47	1.15 ± .73	17.35 ± 2.81	1.65 ± .49	2 ± 0	16.96 ± 1.51

The six psycho-pedagogical parameters of tree Neuropedagogical methods named "vary the access to information; mind map and memory cards" vary in a highly significant way ($p < 0.001$) between the beginning and the end of each experiment at the levels of the averages of the scores going from 9.24% to

706.25%. Indeed, at the level of the averages of the attention scores, for the neuropedagogical method "Contextualization of learning" there is a significant increase of 45.98% [=((2-1.37)/1.37)×100%] at the post-test compared to the pre-test corresponding to 1.37±.567 vs. 2±00. We also noticed a significant increase of 35.13% in active engagement, 35.9% in the number of words memorized, 9.24% in the error feedback, 31.75% in satisfaction with the method, and 71.02% in the written test.

For the neuropedagogical method called "memory card," the average scores of the psycho-pedagogical parameters vary 42.85% for attention, 37.31% for commitment, 38.90% for the number of keywords memorized, 706.25% for the return on error, 84% for the satisfaction of the students toward the method, and 28.62% for the results of the written test.

Finally, the average scores of the "focused on the essentials" method, whose results are also highly significant, vary from 13.01% for the parameters of return on error, 19.01% for the parameters of attention, and 19.52% for the written test, to 25.63% for the number of keywords memorized, 29.87% for the satisfaction of the students toward the method. For the three other methods "role-playing game, playful activity, and “expert student," the psycho-pedagogical parameters vary significantly ($p<0.05$) to different degrees between the beginning and the end of the experiment.

Table 4 Effect of measured variables between pre-test and post-test (Developed by the authors)

Experienced methods			
Psycho-pedagogical parameters	**Contextualization of learning**	**Memory cards**	**Focused on the essentials**
Attention	45.98 %***	42.85%***	19.01%*
Active engagement	35 .13%**	37.31%***	-3.36%
Error correction	9.24%	706.25 % ***	13.01 %
Number of key words memorized	35.9%***	38.90 % ***	25.63 % ***
Results of the written test	71.02%*	28.62%***	19.52%***
Satisfaction with the method of the students	31.57%***	84%***	29.87%**

* P < .05; ** P < .01; *** P < .001

The relationship between the pre-test and post-test is approximately linear for each treatment group. It is also clear that the linear relationship is similar for all three treatment groups.

Throughout this study, we have sought to highlight the effects of introducing neuroeducational data into the school and, more specifically, into classroom learning situations. The results obtained are promising for the “Contextualization of learning” neuropedagogical method.

3.1. “Contextualization of Learning” Neuropedagogical Method

The term "contextualized" refers to a didactic situation that aims to bring learning in the classroom as close as possible to learning in the natural environment.

“The most important factor influencing learning is what the learner already knows” [10]. Indeed, the teacher is called upon to provide authentic tasks during a learning situation. These situations are the base material for developing skills in learners [11]. The hypothesis of this experiment originates from the theory of situated cognition [12]. Humans reorganize the world so that it makes sense to them, thanks to brain plasticity and the brain artifact interface.

Links exist between different temporalities in which neural and material construction and remodeling can occur [13]. Contextualization refers to authentic and complex learning situations where the context of learning acquisition is not very far from the learner’s experience, which will help him/her. First, to better represent the situation and to decipher the information that has acquired a meaning concerning the data, he/she will proceed to process them thanks to the organization that they have provided for the end, he/she will link them to the previous knowledge, to encode them into the memory.

During this encoding process, the learner constructs meaning from the information communicated to him [14]. If prior knowledge is relevant, convenient, strongly represented, and well-mastered, the learner could easily use it during the learning task (source task) to solve new problems (target task). “The encoded, stored, and organized knowledge serves as a kind of basis for the transfer since it is this knowledge that will later be recalled and activated when performing the target task, depending on the perceived similarity between the source task” and “target task” [15]. The results achieved effectively show an improvement in learning since the indices of the psycho-pedagogical parameters measured (attention, active engagement, number of words memorized, writing results) showed a significant increase varying between 9.24% and 71.02; these results corroborate the hypothesis that it is easier to reactivate the knowledge learned if the learning situation proposed to the students is contextualized, i.e., reflects a certain complexity corresponding to the real world and refers to the environment in which the task allows the creation of links with other situations with similar experiences.

The brain remembers facts and skills better when related to authentic contexts [16, 17].

From an educational neuroscience perspective, the constant exploitation of the environment leads to the progressive selection of neuro-cultural circuits specific to each individual [18]. The transition from working memory to long-term memory is made thanks to the hippocampus, which compares the recent information with that already recorded before sending it to the cortex. Memory traces are underpinned, thanks to synaptic plasticity, by marking neuronal networks distributed throughout the brain but perfectly specified, serving as a support for spatiotemporal patterns of neuronal activity [19]. In other words, during memorization, the hippocampus plays a role in the processing and analysis of information, its novelty, and significance [20], by comparison with information already memorized, and would allow for the marking of the entire network, essentially cortical.

Memory processes are cognitive and neurobiological, and behavioral experiences modify neuronal and synaptic morphology. Synaptic marking is the phenomenon of long-term potentiation that has been demonstrated [21], first in the hippocampus [22], but since then has been found in other structures, particularly at the cortical level.

For memory retention and recall, there must be functional changes in the corresponding synapses. The knowledge stored in memory forms semantic networks, groupings of interconnected information units called nodes. The activation of a node in a network triggers the activation of its associated nodes [23].

Any new learning, which occurs in a given context, activates specific neurons, which in turn will tend to connect to the neurons of the desired learning. The fact of learning specific knowledge in particular conditions will make more likely the reactivation of this knowledge learned in this same context, corollary, it will be more difficult to reactivate this knowledge learned in a different context, as proved by the two experiments of the olfactory discrimination [24; 25].

In other words, the more learning is done in connection with the learner's experience and through authentic situations, the easier it would be to reactivate the knowledge learned in this situation; this will help a semantic organization that is necessary for the encoding and transformation of a perceived external stimulus into an internal representation in the memory and make the neural network stronger, which would facilitate the retrieval of information.

This explains the highly significant improvement between the pre-test and post-test of our experiment, which reached 35.9% for memorized keywords and 71.02% for written tests; this dynamic contextualization promotes significant learning and helps establish relationships between old and new meanings. Our explanation for the increase in learner engagement in this experiment by a highly significant 45.98% is that: Attention and encoding are the first steps of mental representation and that at the level of the hippocampus, attention selects in the memory, clues, elements, and experiences that will make it possible to give meaning to the (source task) and to act according to this meaning to solve (the target task). This mechanism is partly mediated by dopamine and involves an increase in neuronal synchronization in the frequency of the gamma band; this synchronization activity leads to improvements in synaptic strength involved in the stabilization of hippocampal representations [26].

These contextualized learning situations, or those that integrate the characteristics of a task carried out in an actual context, or of the learner's experience, allow him to grasp a certain complexity corresponding to reality and give meaning to the information communicated to him.

3.2. "Memory Cards" Neuropedagogical Method

This method consists of taking tests frequently, answering questions often, and competing to give the correct answers.

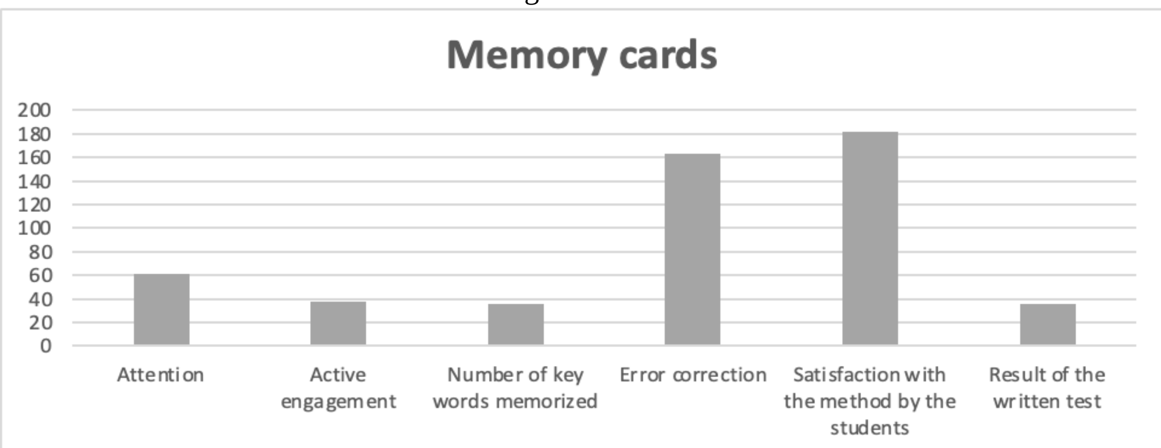

Fig. 1 Percentage fields of variations in psycho-educational parameters between the start and the end of the experiment in (%) for the "Memory cards" (Developed by the authors)

Research has shown that, in addition to being a widely used tool for assessing learning, testing can also be an effective method for increasing the long-term recovery of the subjects studied [27, 28, 29, and 30].

Frequent retrieval practice and usage of background knowledge alone are more effective than retraining and are efficient tools for promoting learning. Feedback from perceptual information-seeking activities and goal-directed behavior may have priority for entry into the episodic system [31]. Better difficult but successful retrievals are better for memory than easier and successful retrievals [32].

Indeed, training in memory retrieval facilitates learning because it allows the activation of the neurons linked to it and consolidates the synaptic connection of its neurons. The percentage of recall evolves as a function of the number of memory retrieval tests, and this is related to the success rate and the level of retention of information, while the probability of recalling in a given period the elements learned increases as a function of the number of successful retrievals [33].

Our experimentation confirmed the positive effects of the tests on the improvement in long-term retention since the variation in the number of memorized words and written tests increased significantly between the pre-test and the test station by 38.90% and 28.62%, respectively. Test-potentiated learning confirms that there is indeed a test-reinforced leverage effect, i.e., prior testing reinforces the encoding of items not yet retrieved [34]. "The anterior insula plays a key role in signaling the salience of the previously tested items and invokes relative deactivation of default network regions while activating prefrontal processing resources. Higher activation in the orbital parts of the left inferior frontal gyrus and left hippocampus may reflect increased encoding activity [35]. Strengthening neural connections reduces activity in the prefrontal cortex, which may indicate that the task becomes easier and less overwhelming to the brain, thereby solidifying learning and reducing forgetting [36].

This being said, a motivational context could improve the efficiency of the brain's hedonic system to promote learning; the higher the number of correct responses, the more dopamine there is in the striatum [37].

Indeed, our method maximized feedback through competition between learners to give the correct answer to review their knowledge; this feedback is essential for teaching new skills and helps keep learners engaged and to support their perseverance in complex learning tasks.

The striatum is a critical region in the modulation of learning by achievement motivation. It is involved in performance-related feedback learning, which explains the 37.31% improvement in active engagement between the pre-test and post-test of our experiment; neural activity during a feedback situation depends on the type of response (reward or punishment) as well as cognitive flexibility; Positive feedback is more active than negative feedback, and the orbitofrontal cortex responds to emotionally meaningful feedback, while the ventrolateral cortex responds to emotionally meaningful feedback.

The prefrontal cortex is involved when it is necessary to plan a response to negative feedback; striatal dopamine is selectively released during learning based on correlative feedback, which implicates the striatum and its dopamine connections in mediating learning with correlative feedback. Goals, objectives, and expectations can affect the striatal processing of cognitive feedback, as can the modulation of reward responses by subjective value [38].

The results obtained for the return on error and attention that recorded a significant increase of 706.25% and 42.85% might be because this Neuropedagogical method is based on self-regulation since each learner expects his/her bonus, which promotes self-determination and vigilance in the control of performance by promoting awareness of the distress related to errors, which stimulates the capacity for self-regulation, increasing attention and emotional.

Reactions to errors due to the well-defined performance of the anterior cingulate cortex, self-determination has a neural basis that plays an essential role in cognitive control and optimal performance [39].

3.3. "Focused on the Essentials" Neuropedagogical Method

Large paragraphs of text often lead to cognitive overload and confusion for learners, who become unable to process the swarm of information presented to them, let alone grasp the critical point; this is what makes instruction need to consider the limitations of working memory so that long-term memory efficiently stores information. Learning is the development and automation of cognitive schemas, "a cognitive construct organizing pieces of information in terms of how they will be processed" [40].

This method aims to help the brain organize knowledge to develop mental structures that better inform our understanding; when a large amount of information communicates beyond processing capacity, several elements compete for space and can cause loss and decreased performance [41]. This method hypothesizes that it can help facilitate information acquisition by reducing it to the essential and structuring it to grasp the semantic relationships and elaborate the links.

Cognitive load theory suggests that effective instructional materials facilitate learning by directing cognitive resources to information relevant to learning [42]. Information overload and cognitive overload can interfere with the cognitive and metacognitive processes necessary for knowledge construction [43]. The results obtained in our experimentation confirm our hypothesis because the results of the written tests recorded an improvement of 19.52% between the pre-test and the post-test.

Effective reorganization can alleviate task difficulty and optimize performance because cognitively less demanding tasks can elicit greater recruitment of neurons from the lateral prefrontal cortex [44] which is intimately related to cognitive load and stress management and plays roles ranging from internal processing of emotions and internal states (mentalization) to memory retrieval, prospective memory, attentional control, and relational awareness [45], the lateral area of its anterior part seems to play a general role in the strategic recording of memory information, injuries in this region can interfere with people's abilities to switch between tasks, remember where an instruction comes from or adapt to rule changes [46], more specifically the dorsolateral prefrontal cortex promotes the successful formation of long-term memory under its role in organizing the elements that are active in mobile memory by enhancing inter-element associations [47, 48, 49]. fMRI has shown increased activation of the lateral prefrontal cortex for these structured sequences. Specifically, the dorsolateral and ventrolateral prefrontal cortices were preferentially activated for structured sequences during encoding [50].

Another study examining the processing of structured and unstructured sequences reported that consolidating information to reduce the load on the mobile memory or "chunking," increased the recruitment of the ventrolateral prefrontal cortex; this increase is also observed during information retrieval [51]. This explains our results, which show a significant increase in memory by 25.63% and attention by 19.01%. Cognitive overload would remarkably weaken the effectiveness of the self-monitoring system and the awareness of the error [52] that perfectly agrees with our results, which show that indeed the error feedback showed a significant increase of 13.01% by reducing these cognitive overload learners lost in the information overload in the pre-test used much less systematic exploration and made more errors than less tired participants in the post-test they had difficulties in focus their attention, plan, and change strategy adaptively when faced with unsatisfactory results.

4. Conclusion

The results of the three experiments carried out in the classrooms showed their significant positive effects on the main elements measured; there was a considerable increase of 706.25% in the students' ability to have feedback on the errors made when using the memory cards. This self-regulation encourages optimal performance according to the Bayesian model of the functioning of our brain and its learning algorithms, which constantly seek out errors, 2% in the experiment of arrowing the essential, which proves that this method lightens the cognitive load of the students, which allows better recovery of information at the time of the exams. Our experiments provide a model of information processing according to the data of neuroeducation by using the operational cards that require a great investment of neuroscientific data and their deployment to propose teachers' tools that can help them innovate their practices and improve learning. The main objective of this article, as well as that of the previous one [53], is similar and consists in reconsidering the display of bridges between neuroscience and education, two entities that seemed so divergent from each other. These articles bring a plus to educational neuroscience through which a junction between these two fields could be established, thus offering a revolutionary vision of learning.

The articles claim that the relationship is indeed bidirectional, encouraging educators and educational researchers to tap into neuroscientific findings, theories, and methods and to question the bilateral and reciprocal interactions between the two disciplines, neuroscience, and education. The contribution of our tested Neuropedagogical methods has given satisfactory results; it is nevertheless essential to consider certain limitations related to the fact that the teachers who participated in our study had no previous training in neuro-education; knowing how the brain processes information and what the cognitive and metacognitive processes involved in learning would be beneficial. However, this should not overshadow all the other insights necessary for the pedagogical act, nor should it make teachers specialists or experts in the functioning of the nervous system. Introducing cognitive neuroscience into the school world would be a beneficial opportunity insofar as it would make it possible to question and renovate the system in its entirety. Considerable effort is needed to better understand the school's success multidimensionality and to ensure effective and relevant pedagogical intervention [54]. We do not claim that there is a miracle cure for learning problems in the classroom, but the results obtained and the explanations proposed can shed light on pedagogical practices, pending further consideration of the analysis of these practices from a neuropedagogical viewpoint.

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