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IMPORTANCE OF NEUROIMAGING IN NEUROPEDAGOGY: ADVANCES AND CHALLENGES FOR BRAIN SCIENCE-BASED EDUCATION

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Abstract.

This study analyzes the need to incorporate neuroimaging into neuropedagogy, examining educators' perceptions of its importance, advances and challenges. A mixed design was used with 350 teachers from Spain, Brazil, Colombia, Mexico and Paraguay. A quantitative questionnaire was used (Likert scale 1-5) with 20 items distributed in four dimensions: Neuropedagogy, Neuroimaging, Advances and Challenges. It was complemented with a focus group of 10 participants. Descriptive, correlational and regression analyses were conducted, along with a qualitative thematic analysis. Quantitative analyses revealed positive perceptions in all dimensions, with significant correlations between Neuropedagogy, Neuroimaging and Advances (r between 0.685 and 0.743, $p<0.01$). Regression showed Neuroimaging to be the strongest predictor of Neuropedagogy rating ($\beta=0.456$, $p<0.001$). Qualitative analysis identified enthusiasm for Neuropedagogy and Neuroimaging, but also challenges in their practical application. The findings underscore the perceived importance of neuroimaging in neuropedagogy, but also reveal significant barriers to its effective implementation. The need for further teacher training, resource development, and ethical guidelines for the use of neuroimaging in education is highlighted. Future research is suggested to translate neuroimaging findings into concrete pedagogical strategies and evaluate their effectiveness in various educational contexts.

Keywords: neuropedagogy, neuroimaging, advances, challenges, education

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1.-Introduction

Neuropedagogy emerges as an interdisciplinary field that integrates advances in neuroscience with educational practices, with the aim of optimizing teaching and learning processes. This discipline is based on the premise that a deep understanding of brain functioning can lead to the development of more effective pedagogical strategies adapted to the cognitive and emotional needs of students. Hernández &De Barros (2023) postulate that neuropedagogy seeks to apply neuroscientific knowledge to promote quality education based on scientific evidence about brain functioning. This perspective is supported by Esteban et al. (2023), who stress the importance of neuropedagogy in the design of teaching methodologies that are aligned with the cognitive and emotional processes of students. In this context, Campos (2010) argues that neuroeducation, a concept closely linked to neuropedagogy, provides educators with a deeper understanding of the brain mechanisms involved in learning, memory and information processing. This author emphasizes that the application of neuroscientific principles in education not only involves the implementation of new techniques, but also the creation of learning environments that enhance optimal brain development. Mora (2013) expands this perspective by introducing the concept of "neuroeducation" as an innovative paradigm in brain-based teaching. According to this author, neuroeducation offers valuable tools for the early identification of learning difficulties of neurological or psychological origin, as well as for the development of strategies to improve students' attention, memory and motivation.

The importance of basing educational practices on neuroscientific evidence is underlined by Tokuhama-Espinosa (2011), who defines neuroeducation as the systematic application of findings from neuroscience, psychology and pedagogy to improve teaching and learning processes. This multidisciplinary approach seeks to build a bridge between brain research and educational practice. In the field of higher education, Carew & Magsamen (2010) have explored the application of neuroscientific principles for the improvement of teaching and learning practices. These researchers emphasize the importance of designing educational environments that stimulate brain plasticity and foster the formation of meaningful neural connections, crucial aspects for effective and lasting learning.

The convergence of these perspectives underscores the transformative potential of neuropedagogy in the educational field. By integrating knowledge about brain functioning with pedagogical practices, this discipline promises not only to improve academic outcomes, but also to foster more holistic cognitive and emotional development of students. However, it is crucial to recognize that the application of neuropedagogy requires continuous training of educators and rigorous evaluation of its methods and results to ensure its effectiveness and relevance in various educational contexts. For this reason, it is essential to start from an exact definition of the term neuropedagogy, provided by Hernández & De Barros (2024), who define it as the science that studies education from a neuroeducational perspective, with the aim of configuring the neurotheory and neuromethodology of education, as well as its practice, which is neurodidactics.

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Neuroimaging stands as a cornerstone in the field of neuropedagogy, providing a unique window to observe and understand the brain processes underlying learning. This technology has revolutionized our ability to study the brain in action, offering invaluable insights into how information is processed and how brain structures are modified in response to different educational stimuli. De Barros (2023) highlights the crucial role of neuroimaging as a techno-pedagogical tool, arguing that it allows educators and researchers to noninvasively visualize brain activity during specific cognitive tasks. This direct observational capability has significantly expanded our understanding of the neural mechanisms that underpin learning and memory. Among the neuroimaging techniques most relevant to neuropedagogy, functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) occupy a preeminent place. Hernandez (2022) points out that these technologies allow real-time observation of the activation of different brain areas during various learning tasks, providing an empirical basis for the design of more effective and personalized educational strategies.

The application of neuroimaging in educational contexts has led to significant discoveries about brain plasticity and its relationship to learning. According to Goswami (2006), neuroimaging studies have demonstrated how educational experiences can modify brain structure and function, supporting the importance of enriched learning environments and teaching methodologies tailored to the individual needs of students. Ansari et al. (2012) highlight the potential of neuroimaging to identify neural biomarkers associated with specific learning difficulties. This early diagnostic capability could enable more timely and effective educational interventions, personalizing support for students with special educational needs. However, it is crucial to recognize the limitations and ethical challenges associated with the use of neuroimaging in educational settings. Bowers (2016) cautions against the risk of overinterpretation of neuroimaging data and emphasizes the need for a critical, multidisciplinary approach in the application of these findings to educational practice.

The integration of neuroimaging into educational research also raises new possibilities for the evaluation of teaching methodologies. Thomas et al. (2019) argue that neuroimaging techniques can provide objective measures of the effectiveness of different pedagogical approaches, complementing traditional measures of academic performance. Advances in the application of neuroimaging to neuropedagogy have been remarkable in recent years, opening new frontiers in the understanding of teaching-learning processes. De Barros & Hernandez (2022) highlight how the integration of neuroscience, neuroeducation and technology is revolutionizing our understanding of learning. One of the most significant advances has been the identification of brain activity patterns associated with different learning styles and cognitive processes. Gabrieli (2016) notes that these findings have enabled the development of more personalized educational strategies tailored to the individual needs of learners. In addition, neuroimaging has provided scientific evidence on brain plasticity and the importance of enriched learning environments. Butterworth & Tolmie (2014) argue that these findings have led to the implementation of educational

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practices that foster appropriate cognitive and emotional stimulation to enhance learning.

Despite significant advances, the application of neuroimaging in neuropedagogy faces important challenges. Hernandez (2023) identifies as one of the main challenges the gap between neuroscientific research and its practical application in the classroom. It is imperative to develop methods to translate neuroimaging findings into concrete and accessible pedagogical strategies for educators. Another crucial challenge is the training of teachers in neuroscience and neuroimaging. De Barros (2022) emphasizes the need for teacher training that incorporates this knowledge so that educators can take full advantage of neuropedagogy. Howard-Jones et al. (2016) point out the ethical and privacy challenges related to the use of neuroimaging in educational settings. It is critical to establish clear guidelines for the responsible use of this technology and to protect the privacy of students.

With all of the above, neuropedagogy, supported by advances in neuroimaging, is transforming our understanding of teaching and learning processes. Neuroimaging has emerged as a fundamental tool in this field, making it possible to visualize and study brain activity during learning. However, the practical application of this knowledge faces significant challenges, including the need to bridge the gap between research and educational practice, adequate teacher training, and consideration of ethical and privacy issues.

The research presented here shows the need for the union between neuropedagogy and neuroimaging, for the design of the research lines that will be developed in the coming years.

3.-Methods

This study adopts a mixed design, combining quantitative and qualitative approaches. The quantitative component follows a non-experimental, descriptive, explanatory, correlational and regression design. The qualitative component incorporates a focus group. This mixed approach allows us to comprehensively address the general objective of analyzing the need to incorporate neuroimaging into neuropedagogy.

Participants

The quantitative sample, selected by convenience and criterion, consisted of 350 teachers with research experience in neuroeducation and neuropedagogy. The geographical distribution was: 168 from Spain, 79 from Brazil, and 103 from Colombia, Mexico and Paraguay. For the qualitative phase, a focus group was formed with 10 teachers randomly selected from the main sample.

Instruments

-Quantitative questionnaire

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A Likert scale questionnaire (1-5) was designed with 20 items, equally distributed in four dimensions: Neuropedagogy, Neuroimaging, Advances and Challenges. The construction was based on an operationalization table, aligning the items with the dimensions and specific objectives. The reliability of the questionnaire is 0.93 (Cronbach's alpha) which is considered excellent.

Construct validity was examined through an exploratory factor analysis. The Kaiser-Meyer-Olkin (KMO) test yielded a result of 0.807, and Bartlett's test of sphericity was significant ($p < 0.000$), indicating the adequacy of the data for factor analysis.
The analysis of communalities revealed three items with very high values and two with lower values, although higher than 0.7. Specifically:
Items with very high communalities:
"Neuropedagogy facilitates understanding of individual differences in learning." (Dimension A)
"Neuroimaging is a crucial tool for understanding the cognitive processes involved in learning." (Dimension B)
"Collaboration between neuroscientists and educators is essential for the advancement of neuropedagogy." (Dimension C)

Items with lower communalities but higher than 0.7:
"It is difficult for teachers to keep up with advances in neuroscience." (Dimension D)
"There is a lack of adequate resources to apply neuroscience knowledge in education." (Dimension D)
Although these last two items presented lower communalities, it was decided to retain them in the analysis because of their theoretical relevance and because their values exceeded the threshold of 0.7. The analysis of variance with Varimax rotation confirmed the factorial structure of the questionnaire without the need to eliminate items, supporting the construct validity of the instrument.

-Focus group
A script based on 8 direct questions extracted from the items of the questionnaire was used, covering the four dimensions of the study. This format allowed for a more dynamic and in-depth group discussion on the central themes of the research.

Procedure

The study was developed in the following phases:

1. Design and validation of the questionnaire:
   - Initial construction based on the operationalization table.
   - Validation of content by expert judges.
   - Conducting a pilot test for final adjustments.

2. Application of the questionnaire to the selected sample.
3. Conducting a focus group with 10 randomly selected teachers.
4. Integrated quantitative and qualitative data analysis.

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Ethical considerations

The study was conducted under the protection of the corresponding institutional ethics committee. All participants were informed of the purpose of the study and provided informed consent prior to participation. Confidentiality and anonymity of the data collected in all phases of the study were guaranteed.

4.-Results

The descriptive results provided by the quantitative questionnaire are shown in table 1.

Table 1
Descriptive results

Dimension	Media	Median	Asymmetry	Kurtosis
Neuropedagogy	4.12	4.20	-0.68	0.45
Neuroimaging	3.87	4.00	-0.32	-0.21
Advances	3.95	4.00	-0.45	0.18
Challenges	3.76	3.80	-0.15	-0.38

The Neuropedagogy dimension shows a tendency towards positive ratings, with a slight negative skewness indicating a concentration of responses in the higher values of the scale. For the Neuroimaging dimension, a generally positive rating is observed, with a slightly asymmetric distribution to the left and a platykurtic kurtosis, suggesting a somewhat flatter than normal distribution. The Advances dimension presents a positive assessment, with a moderate negative skewness and a kurtosis close to the normal distribution. In the Challenges dimension, a slightly positive assessment is observed, with a slight negative skewness and a platicurtic distribution, indicating a somewhat greater dispersion in the responses.

These results suggest a generally positive perception across all dimensions, with Neuropedagogy receiving the highest ratings and Challenges showing greater variability in responses. The negative skewness across all dimensions indicates a general trend toward above-average ratings.

On the other hand, the data analysis performed with the Kruskal-Wallis test shows that the data distribution is normal, so a Pearson's r correlation analysis is performed (table 2).

Table 2
Correlation analysis

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Dimension	Neuropedagogy	Neuroimaging	Advances	Challenges
Neuropedagogy	1.000	0.721**	0.685**	0.412*
Neuroimaging	0.721**	1.000	0.743**	0.389*
Advances	0.685**	0.743**	1.000	0.456*
Challenges	0.412*	0.389*	0.456*	1.000

The results of the correlation analysis reveal significant associations between all the dimensions of the study. Strong, positive correlations are observed between Neuropedagogy, Neuroimaging, and Advances, with coefficients ranging from 0.685 to 0.743 ($p < 0.01$). This suggests a close relationship between these three dimensions, indicating that participants who positively value one of these areas tend to positively value the other two.

Finally, the regression analysis performed is shown in table 3.

Table 3
Regression analysis

Predictor Variable	Coefficient β	Standard Error	t	p	VIF
(Constant)	0.542	0.183	2.962	0.003	-
Neuroimaging	0.456	0.052	8.769	< 0.001	2.341
Advances	0.312	0.055	5.672	< 0.001	2.487
Challenges	0.104	0.041	2.537	0.012	1.325

The regression model was statistically significant ($F(3, 346) = 191.45$, $p < 0.001$), explaining 62.0% of the variance in the perception of Neuropedagogy (adjusted $R^2 = 0.620$).
The Neuroimaging dimension emerged as the strongest predictor of Neuropedagogy ($\beta = 0.456$, $p < 0.001$), followed by Advances ($\beta = 0.312$, $p < 0.001$). This suggests that perception of the importance of neuroimaging and recognition of advances in the field are strongly associated with a positive appraisal of neuropedagogy. Challenges also proved to be a significant predictor, although with a smaller impact ($\beta = 0.104$, $p = 0.012$). This indicates that awareness of challenges in the field also contributes, albeit to a lesser extent, to the valuation of neuropedagogy. The Variance Inflation Factor (VIF) values for all independent variables are below 3, suggesting that there are no multicollinearity problems in the model.
In summary, these results indicate that perceptions of neuropedagogy are strongly influenced by appreciation of neuroimaging and recognition of advances in the field, with a minor but significant contribution from awareness of existing challenges.

Regarding the analysis of the focus group results, the thematic analysis of the transcripts revealed four main themes, aligned with the dimensions of the study:

Perception of Neuropedagogy: Participants expressed a general consensus on the importance of neuropedagogy in teaching practice. A recurring theme was the need to integrate neuropedagogical principles into teacher education. As one participant expressed:

"Neuropedagogy has transformed my approach to teaching. I strongly believe that it should be a mandatory component of all teacher education." (GF-P3)

However, some participants also pointed out the gap between theory and practice:

"I understand the importance of neuropedagogy, but sometimes it is difficult to translate this knowledge into concrete strategies in the classroom." (GF-P7)

Role of Neuroimaging

Most participants recognized the potential of neuroimaging in education, although they expressed varying opinions about its practical applicability. One teacher commented:

"Neuroimaging studies offer us a unique window into the learning brain. However, interpreting these results and applying them in the classroom remains a challenge." (GF-P2)

Another participant added:

"Neuroimaging is fascinating, but I worry that it could lead to 'neuromania' if not interpreted correctly in the educational context." (GF-P9)

3. Advances in the Field

Participants showed great interest in recent advances in educational neuroscience. Many expressed enthusiasm for the new possibilities that these advances offer:

"Discoveries about brain plasticity and neurogenesis in adults have completely changed my perspective on the learning potential of my students." (GF-P5)

However, concern was also expressed about the speed of integration of these developments:

"I feel there is a significant gap between research findings and their implementation in educational policy and practice." (GF-P1)

4. Challenges and Limitations

Participants identified several challenges in the application of neuropedagogy and neuroimaging in education. The most frequent themes included:

a) Lack of adequate training:
"I am overwhelmed by the amount of neuroscientific information available. We need more training to interpret and apply this knowledge correctly." (GF-P8)

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b) Resource limitations:
"Neuroimaging technology is fascinating, but how can we access it in educational contexts with limited resources?" (GF-P4)

c) Ethical considerations:
"I am concerned about how we can use neuroimaging in education without invading students' privacy or creating unnecessary labels." (GF-P6)

Finally, the focus group revealed a high level of interest and enthusiasm for neuropedagogy and neuroimaging among teachers. However, it also revealed significant challenges in the practical application of this knowledge. Participants emphasized the need for more robust training in educational neuroscience and clear guidelines for ethical and effective implementation of these approaches in the classroom.

5.-Conclusions

The results of this research underline the critical importance of neuroimaging in the field of neuropedagogy, revealing a generally positive perception among educators about its potential to transform educational practices. Quantitative analysis demonstrated significant correlations between the Neuropedagogy, Neuroimaging and Advances dimensions, indicating a close interrelationship between these aspects in teachers' perceptions. Neuroimaging emerged as the strongest predictor of appreciation of neuropedagogy, followed by Advances in the field. This suggests that understanding and appreciation of neuroimaging techniques are intimately linked to the adoption and valuing of neuropedagogical approaches in education.

The qualitative focus group analysis revealed a high level of enthusiasm for neuropedagogy and neuroimaging, but also revealed significant challenges. Prominent among these were the need for more robust training in educational neuroscience, the difficulty in translating neuroimaging findings into concrete pedagogical practices, and ethical concerns related to the use of these technologies in educational settings. These findings suggest that while there is widespread recognition of the potential of neuroimaging to enrich neuropedagogy, there are still significant barriers to its effective implementation. The gap between neuroscience research and its practical application in the classroom emerges as a crucial challenge that requires attention.

In conclusion, this research highlights the need for greater integration between neuroimaging and neuropedagogy, pointing toward a future where education is more grounded in brain science. However, to realize this potential, a concerted effort is required in teacher training, the development of adequate resources, and the creation of clear ethical guidelines for the use of neuroimaging in educational contexts. Future research should focus on developing practical methods for translating neuroimaging findings into concrete pedagogical strategies, as well as evaluating the efficacy of

neuroimaging-based educational interventions in diverse contexts and student populations. In addition, it is crucial to continue the interdisciplinary dialogue between neuroscientists, educators, and policy makers to ensure that advances in neuroimaging are effectively translated into tangible improvements in the quality of education.

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