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EEG-BASED INSIGHTS INTO INTERNAL LEARNING STATES: A STATE-OF-THE-ART REVIEW TOWARD A NEURO-PEDAGOGICAL FRAMEWORK

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Abstract: *The growing convergence of educational neuroscience, neurotechnology, and pedagogy has strengthened interest in neuropedagogy as a framework for understanding the internal conditions that shape learning. Within this context, electroencephalography (EEG) has emerged as a relevant method for investigating cognitive and emotional processes due to its high temporal resolution and applicability in dynamic educational settings. This review examines the role of EEG in the study of internal learning states, with particular attention to attention regulation, stress, affective processes, self-regulation, and internally oriented attention. The paper outlines the conceptual foundations of neuropedagogy, reviews EEG as a methodological tool for educational research, and synthesizes current evidence on cognitive-emotional asymmetries, stress and anxiety markers, depression-related neural patterns, conscientiousness-related oscillatory variation, and candidate spectral indicators of internal attentional states. The review highlights both the growing interpretive potential of EEG and the continuing challenges related to construct validity, psychometric rigor, ecological relevance, and ethical use. On this basis, the paper proposes a future-oriented neuro-pedagogical framework in which EEG data are treated as context-sensitive indicators that can enrich educational research when integrated with validated psychological constructs and multimethod designs.*

Keywords: *neuropedagogy; electroencephalography; internal learning states; educational neuroscience; neuro-pedagogical framework.*

Foundations of neuropedagogy and internal learning states

Positioned within a broader educational research landscape that has recently engaged with non-formal learning, dramatic pedagogy, digital classroom practices, teacher–parent communication, reading motivation, emotional development in early education, mentoring in lifelong learning, and psychosocial determinants of wellbeing and adaptation, the present review advances this line of inquiry by examining how EEG-based evidence may contribute to a neuro-pedagogical understanding of internal learning states (Dughi, 2020; Dughi & Bold, 2022; Dughi et al., 2024; Dughi et al., 2024; Dughi et al., 2024; Dughi & Coșarbă, 2025; Dughi et al., 2025; Dughi et al., 2025).

Neuropedagogy has emerged as an interdisciplinary field situated at the intersection of educational sciences, cognitive neuroscience, developmental psychology, and learning theory, with the explicit aim of refining educational understanding through empirically grounded insights into brain–behavior–learning relationships. Rather than reducing pedagogy to neurobiological determinism, contemporary neuropedagogy seeks to articulate a multi-level explanatory model in which neural dynamics, cognitive processing, affective modulation, and contextualized instructional practices are treated as mutually constitutive dimensions of the learning process. In this sense, educational neuroscience has gradually moved from a predominantly translational ambition—bringing laboratory findings into the classroom—toward a more dialogical framework in which pedagogical questions themselves shape neuroscientific inquiry (Gola, 2024; Williamson et al., 2025; Friedman et al., 2026). This repositioning is essential because the educational relevance of brain-based evidence does not lie in isolated neural correlates, but in its capacity to inform theoretically coherent and pedagogically meaningful interpretations of learning processes as they unfold in real environments (Elouafi et al., 2021; Piddubna et al., 2023).

Within this broader epistemic shift, neuropedagogy increasingly relies on the premise that learning is not merely the outcome of external instruction or observable performance, but is continuously mediated by internal learning states. These states include dynamic constellations of attention, arousal, emotional valence, cognitive control, motivational orientation, and self-regulatory readiness that shape how learners perceive, process, retain, and apply information. A cognitive

neuroscience perspective on learning emphasizes that instructional efficacy cannot be fully understood without considering these internal mediating processes, because the same pedagogical stimulus may be differentially encoded depending on the learner's psychophysiological condition at a given moment (Lotfi et al., 2023). Accordingly, the neuropedagogical project is not limited to identifying "where" learning happens in the brain, but extends to understanding "under what internal conditions" learning becomes more or less probable, stable, adaptive, or transferable (Gola, 2024; Friedman et al., 2026).

The conceptualization of internal learning states draws support from several complementary traditions. From a neuropsychological perspective, the Vygotskian-Lurian approach foregrounds the systemic organization of higher mental functions and the developmental interdependence of cognition, regulation, and mediated action. In this framework, attention, executive control, and learning difficulties are not treated as isolated traits, but as functionally organized outcomes of dynamic neural and sociocultural processes (Akhutina & Pylaeva, 2012). From an embodied and phenomenological standpoint, the mind cannot be separated from the lived body and its environmental embedding; thus, internal states are not merely intracranial events but organism–environment configurations that modulate perception, intentionality, and action (Fuchs, 2017). These perspectives converge in supporting a non-reductionist neuropedagogy: one that acknowledges the relevance of neural processes while resisting simplistic one-to-one mappings between brain signals and educational constructs.

This theoretical caution is particularly important in a field increasingly shaped by rapid technological expansion. The educational deployment of neuroimaging and neurotechnology has encouraged renewed interest in the possibility of accessing covert dimensions of learning that are not fully captured by behavioral assessments or self-report measures. Fernández (2022) argues that neuropedagogy has been significantly strengthened by the integration of neuroimaging methods, which provide a more differentiated view of the temporal and functional architecture of learning-related processes. At the same time, Williamson et al. (2025) note that the contemporary discourse on "learning brains" is inseparable from the rise of neurotechnology and datafication in education, which raises both conceptual and sociotechnical questions regarding how neural information is framed, interpreted, and operationalized within educational systems. Therefore, the development of neuropedagogy requires dual vigilance: methodological openness toward neuroscientific tools and conceptual restraint regarding their pedagogical translation.

Among the internal states most relevant for educational inquiry, attention occupies a central position because it regulates the selection, maintenance, and prioritization of information in relation to task demands. However, attention does not function independently of emotional and motivational conditions. Emotional regulation influences cognitive flexibility, working memory efficiency, and resistance to distraction, while stress-related activation can either mobilize or disrupt learning depending on its intensity, duration, and contextual meaning (Lotfi et al., 2023). In parallel, self-regulation involves the orchestration of attentional control, inhibitory processes, goal maintenance, and reflective monitoring, thereby functioning as a higher-order mediator between neural readiness and pedagogical engagement. Neuropedagogical models that aim to account for internal learning states must therefore integrate these dimensions into a coherent architecture rather than address them in isolation (Elouafi et al., 2021; Vasilieva et al., 2023).

The educational value of such integration has already been illustrated across diverse applied contexts. Piddubna et al. (2023) show that neuropedagogical innovation in schools becomes meaningful when theoretical principles are translated into structured pedagogical practices capable of responding to learners' neurocognitive variability. Similarly, Vasilieva et al. (2023) report that neuropedagogic approaches are associated with the development of primary school students' skills, suggesting that educational design informed by cognitive and affective functioning may contribute to more responsive and differentiated instruction. Beyond mainstream schooling, neuropedagogical reasoning has also been extended to specialized domains such as translation education, where the perception and processing of linguistic-cultural markers are examined through neurocognitively informed pedagogical guidelines (Povoroznyuk et al., 2024). Such applications indicate that neuropedagogy is not restricted to remedial or clinical settings; rather, it is increasingly conceptualized as a general framework for optimizing learning environments across disciplines and learner profiles.

A further expansion of the field can be observed in digitally mediated and high-performance contexts. Nefedchenko et al. (2023) discuss how information and communication technologies can be integrated into educational processes through insights derived from neuroscience, thereby reinforcing the view that learning technologies should be aligned with neurocognitive principles rather than merely adopted for their instrumental novelty. In a different but conceptually related direction, Isidori (2025) advances an AI-enhanced psychopedagogical approach for esports athletes, linking education, well-being,

competitive adaptation, and neurocognitive support. Although these applications differ substantially in domain and purpose, they share a common assumption: effective pedagogical intervention requires sensitivity to the learner's evolving internal state, especially in environments characterized by high informational density, rapid feedback loops, and fluctuating attentional demands.

This line of reasoning also explains the growing interest in neurofeedback and related forms of real-time psychophysiological modulation. The effectiveness of neurofeedback therapy in improving attention, behavior, and emotion regulation among children with autism spectrum disorder, as reported by Istiarsyah et al. (2026), suggests that internal states are not only measurable but, under certain conditions, can be systematically trained or scaffolded. For neuropedagogy, this finding is especially consequential because it shifts the educational focus from static diagnosis to dynamic regulation. If internal states can be monitored and progressively stabilized, then teaching may be reconceptualized not solely as content transmission, but as the intentional shaping of neurocognitive conditions that support learning readiness and adaptive engagement.

In this context, electroencephalography has acquired particular relevance due to its temporal sensitivity and relative accessibility in comparison with other neuroimaging techniques. Although later sections will examine EEG more specifically, its importance must already be acknowledged at the foundational level because it offers a means of approaching internal states as temporally dynamic and fluctuating rather than fixed or inferentially opaque. Earlier work on single-channel EEG signals demonstrated the feasibility of identifying basic mental-state distinctions such as eyes-open versus eyes-closed conditions, thereby illustrating the sensitivity of EEG to state-dependent neural variation (Öner & Hu, 2013). Subsequent reviews of EEG research in early childhood education further established that electrophysiological approaches can contribute to educational inquiry by clarifying developmental patterns of attention and cognitive engagement that are otherwise difficult to capture through conventional assessment alone (Mák et al., 2018).

More recent studies have broadened the scope of EEG-informed inference by investigating cognitive-emotional asymmetries, stress signatures, depressive patterns, conscientiousness-related wave profiles, anxiety assessment, and internally oriented attention. Adochiei et al. (2023) examined individual asymmetries in the power spectral density of EEG waves as markers of cognitive-emotional characteristics, indicating that neural oscillatory organization may reflect meaningful individual differences. Paraschiv et al. (2024)

explored EEG patterns associated with depression, while Adochiei et al. (2024) investigated stress indicators, Bănică et al. (2024) analyzed correlations between EEG wave patterns and conscientiousness, and Paraschiv et al. (2024) validated an anxiety assessment method using the g.TEC Unicorn Hybrid Black alongside psychological testing. Together, these studies do not simply expand the inventory of measurable states; they also reinforce the neuropedagogical argument that learning-relevant functioning is inseparable from affective and dispositional modulation. Complementing these contributions, Manea et al. (2026) proposed a candidate EEG spectral index of internally oriented attention through an exploratory comparison of prayer and relaxation, thereby opening an important line of inquiry into forms of attentional inwardness that may be educationally relevant for reflection, self-regulation, and contemplative learning contexts.

At the same time, the measurement of internal states must be approached with strong psychometric and epistemological discipline. Neural signals are not self-interpreting, and their pedagogical meaning depends on the adequacy of theoretical framing, construct specification, and inferential restraint. Rad et al. (2025) critically examine the illusion of measurement in affective science, arguing that the apparent precision of technologically mediated indicators may conceal unresolved conceptual ambiguities. This caution is directly relevant to neuropedagogy, where there is a persistent temptation to equate measurable neural activity with educationally meaningful constructs without sufficient validation. In a related vein, Paraschiv and Zamfirescu (2025) emphasize the importance of modern psychometric principles for ensuring that the transition from signal detection to construct interpretation remains methodologically defensible. Even broader theoretical work on information, entropy, and communication reminds us that any attempt to interpret neural patterns presupposes a model of signal organization and meaning assignment, rather than a transparent reading of mental reality itself (Paraschiv, 2016).

These concerns extend beyond methodology into the ethical and sociopolitical domain. As neuroscience becomes increasingly entangled with institutional decision-making, issues of privacy, surveillance, data ownership, and normative classification become central rather than peripheral. Grant (2021) shows that the age of neuroscience compels a rethinking of law, state, and market relations precisely because neural data occupy a sensitive position between personhood, autonomy, and governance. In educational settings, this implies that neuropedagogical enthusiasm must be accompanied by careful reflection on the legitimacy, proportionality, and purpose of

any attempt to monitor learners' internal states. The pedagogical utility of neuroscientific information cannot be disentangled from questions concerning consent, interpretive authority, and the risk of converting learners into objects of intensified cognitive surveillance (Grant, 2021; Williamson et al., 2025).

From a broader educational policy perspective, the relevance of internal learning states also intersects with current concerns about inclusion, assessment quality, and differentiated support. Colareza et al. (2026) argue that cognitive education and innovative assessment in primary school must be aligned with learning progressions and systemic challenges such as those highlighted by Romania's OECD–PISA context. This argument is highly compatible with neuropedagogy, which offers a framework for understanding why standardized instructional approaches may fail to address learner variability at the level of attentional stability, emotional readiness, and regulatory capacity. Consequently, the study of internal learning states is not a marginal neuroscientific curiosity; it has direct implications for inclusive educational design, formative assessment, and the creation of environments capable of responding to neurocognitive diversity in a pedagogically responsible manner.

Taken together, the literature indicates that neuropedagogy should be understood as a scientifically ambitious but conceptually disciplined field that seeks to connect neural evidence, cognitive-affective mediation, and pedagogical action. Its foundational premise is that learning is shaped by internal states that are dynamic, embodied, measurable to varying degrees, and educationally consequential. At the same time, the field must avoid reductionism, psychometric naïveté, and technocentric overreach. A robust neuropedagogical framework therefore depends on three interrelated commitments: first, to a theoretically integrative model of internal learning states; second, to methodological rigor in the interpretation of neurophysiological evidence; and third, to ethical and pedagogical reflexivity in the translation of such evidence into educational practice (Fuchs, 2017; Gola, 2024; Rad et al., 2025; Friedman et al., 2026). On this basis, the next step is to examine more specifically how EEG has been used as a methodological tool for investigating cognitive and emotional states relevant to learning, and how this body of evidence may support the development of an EEG-informed neuro-pedagogical framework.

EEG as a Tool for Investigating Cognitive and Emotional States in Learning

Electroencephalography has become one of the most frequently invoked methodological instruments in educational neuroscience due

to its capacity to register neural dynamics with high temporal resolution while remaining comparatively accessible, portable, and adaptable to semi-natural learning contexts. Within neuropedagogical research, EEG is particularly valuable because it allows the investigation of cognitive and emotional processes as they unfold in real time, thus making visible dimensions of learning that are difficult to capture through behavioral observation alone. In contrast to retrospective self-report or post hoc performance indicators, EEG offers access to the fluctuating neural correlates of attention, arousal, cognitive effort, emotional modulation, and internally oriented processing, all of which are central to the study of learning as a temporally structured and state-dependent phenomenon (Fernández, 2022; Gola, 2024; Friedman et al., 2026). Its growing relevance within neuropedagogy reflects a broader methodological shift from static trait-based accounts of learning toward process-sensitive models capable of addressing the moment-to-moment variability of learner engagement.

From a technical standpoint, EEG records electrical activity generated by synchronized postsynaptic potentials, typically through electrodes positioned on the scalp. The resulting signal is analyzed in relation to frequency bands conventionally associated with partially differentiated functional states, most commonly delta, theta, alpha, beta, and gamma rhythms. Although the functional interpretation of these bands must always remain theoretically and contextually constrained, the established literature has repeatedly linked theta activity with memory and executive processes, alpha oscillations with attentional regulation and cortical idling or inhibition, and beta rhythms with alertness, active processing, and cognitive engagement. These associations do not permit simplistic inferential shortcuts, yet they provide a workable starting point for examining the neurophysiological architecture of learning-relevant states (Öner & Hu, 2013; Mák et al., 2018; Fernández, 2022). Within educational contexts, the principal utility of EEG lies not in assigning fixed meanings to isolated waveforms, but in interpreting patterned oscillatory organization in relation to task demands, affective states, and pedagogical conditions.

This methodological position aligns with contemporary educational neuroscience, which increasingly treats learning as a neurocognitively mediated process shaped by interactions among perception, attention, affect, memory, regulation, and context. Lotfi et al. (2023) emphasize that a cognitive neuroscience perspective on learning requires methodological tools capable of capturing how the learner's informational processing system responds dynamically to stimuli, demands, and internal constraints. EEG is well suited to this task because it supports the temporal decomposition of mental processes

without detaching them entirely from ecologically relevant contexts. In classroom-oriented educational neuroscience, this advantage is especially important: pedagogical action unfolds under continuously changing conditions of attentional load, emotional climate, and motivational fluctuation, all of which affect the learner's capacity to process information effectively (Gola, 2024). EEG therefore serves not merely as a measurement device, but as a bridge between neural timing and pedagogical interpretation.

The relevance of EEG for the study of learning also becomes clearer when viewed through developmental and neuropsychological frameworks. The Vygotskian-Lurian tradition conceptualizes higher mental functions as systemic, dynamic, and developmentally mediated, thus encouraging approaches that examine regulation and learning as integrated functional systems rather than isolated capacities (Akhutina & Pylaeva, 2012). EEG contributes to this tradition by offering a way to observe neural signatures associated with attentional readiness, executive modulation, and state variability, thereby complementing behavioral and developmental assessments. At the same time, embodied and phenomenological perspectives remind us that the neural signal is never the whole phenomenon; rather, it indexes organism–environment relations that are lived, situated, and meaningful (Fuchs, 2017). For this reason, the most theoretically coherent uses of EEG in educational inquiry are those that combine electrophysiological data with psychologically and pedagogically interpretable constructs, rather than treating neural activity as a self-sufficient explanatory endpoint.

Historically, even relatively simple EEG paradigms have demonstrated the sensitivity of electrophysiological measures to state differences relevant for cognition. Öner and Hu (2013), for example, showed that one-channel EEG signals can distinguish between eyes-open and eyes-closed conditions, illustrating that neural oscillatory variation can be detected even in minimalist configurations when the state contrast is sufficiently robust. Although such paradigms are methodologically basic, they are conceptually important because they establish the principle that EEG is highly responsive to shifts in vigilance, perceptual orientation, and internal attentional configuration. This principle has since been extended into educational and developmental domains, where more complex paradigms seek to associate neural oscillations with learning readiness, task engagement, and regulatory functioning.

A key contribution to this area is the international overview provided by Mák et al. (2018), who document the increasing use of EEG in early childhood education research. Their review shows that electrophysiological methods have been employed to investigate

developmental aspects of attention, sensory processing, and early cognitive functioning, thereby expanding the methodological repertoire of educational research beyond observational and psychometric approaches. The significance of this body of work lies in its demonstration that EEG can contribute meaningfully to the analysis of learning processes even in young populations, provided that the interpretation of findings remains developmentally informed and methodologically cautious. In other words, EEG is not restricted to laboratory-based adult neuroscience; it has progressively entered educational research as a viable tool for examining neurocognitive precursors and correlates of learning across developmental stages (Mák et al., 2018; Gola, 2024).

More recent scholarship has strengthened the methodological legitimacy of EEG within neuropedagogy by integrating it into broader neuroimaging and neurotechnology frameworks. Fernández (2022) positions neuroimaging as a major epistemic resource for neuropedagogy, arguing that the field benefits from techniques that make learning-related brain activity empirically accessible. Williamson et al. (2025) similarly analyze the expanding role of neurotechnology in the production of "learning brains," showing that the contemporary convergence of educational neuroscience and neurotechnology has reconfigured how cognition is conceptualized, measured, and governed in educational systems. Within this environment, EEG occupies a distinctive place because it combines temporal granularity with relative practicality, making it especially attractive for educational settings where fully controlled neuroimaging conditions are often impossible. However, this same attractiveness can generate overconfidence in the interpretive power of electrophysiological indicators, which is why theoretical discipline remains essential.

In functional terms, EEG has been used to study several categories of states directly relevant to education: attentional allocation, cognitive workload, emotional arousal, stress reactivity, anxiety, dispositional tendencies, and internally oriented attention. These domains are pedagogically salient because they mediate the learner's capacity to engage with instructional input, regulate effort, maintain concentration, and adapt to challenge. Adochiei et al. (2023) explored cognitive-emotional characteristics using individual asymmetries of the power spectral density of EEG waves, illustrating how oscillatory imbalances may index differentiated profiles of affective-cognitive functioning. This line of research is highly relevant for neuropedagogy because it suggests that individual variability in information processing may be accompanied by measurable electrophysiological signatures, thereby

opening possibilities for more nuanced understandings of learner heterogeneity.

The use of EEG to investigate stress-related neural patterns also has substantial implications for educational research. Adochiei et al. (2024) examined EEG patterns as indicators of stress, demonstrating that electrophysiological analysis can support the identification of psychophysiological states that may interfere with learning, concentration, and emotional equilibrium. In educational contexts, stress is not merely an ancillary variable but a core modulatory factor that shapes cognitive performance, memory consolidation, and adaptive functioning. The importance of EEG in this regard lies in its capacity to complement subjective stress reports with temporally sensitive physiological indicators, potentially enhancing the precision of research on academic load, evaluative pressure, and classroom climate. Such contributions are especially useful in neuropedagogical models that conceptualize learning as dependent on the interplay between cognitive demand and emotional regulation (Lotfi et al., 2023; Gola, 2024).

A related area concerns the investigation of anxiety and mood-related states. Paraschiv et al. (2024) validated an anxiety assessment method using the g.TEC Unicorn Hybrid Black alongside psychological testing, thereby illustrating the methodological value of multimodal designs in which EEG-derived indicators are interpreted together with conventional psychological measures. This is a particularly important direction for educational neuroscience because it reduces the risk of attributing excessive construct validity to neural signals in isolation. In a complementary vein, Paraschiv et al. (2024) investigated EEG patterns related to depression, showing that electrophysiological configurations may also be informative with respect to more enduring affective disturbances. Although depression and anxiety are not educational constructs per se, their neural correlates are educationally relevant insofar as they affect motivation, concentration, cognitive persistence, and responsiveness to instruction. EEG thus becomes a tool for examining how affective states intersect with learning-related functioning without collapsing psychological complexity into narrow biological categories.

Beyond stress and anxiety, EEG has also been applied to the study of dispositional characteristics that may influence learning behavior. Bănică et al. (2024) examined the correlation between EEG wave patterns and conscientiousness, suggesting that electrophysiological measures may, under carefully circumscribed conditions, reveal associations between neural organization and stable tendencies related to responsibility, persistence, and behavioral control. For educational

research, such findings are significant because traits like conscientiousness are often linked to academic performance, task completion, and self-regulated learning. Yet the educational interpretation of these results must remain cautious. The value of EEG here does not lie in biologizing personality, but in exploring whether dispositional tendencies have functionally relevant neural correlates that help explain variability in cognitive and regulatory engagement.

An especially promising direction for educational theory concerns the use of EEG to investigate internally oriented attention. Manea et al. (2026) proposed a candidate EEG spectral index of internally oriented attention based on an exploratory comparison of prayer and relaxation. Although the study is not situated directly within classroom pedagogy, its conceptual relevance for education is substantial. Internally oriented attention may play a significant role in reflection, contemplative learning, emotional regulation, meaning-making, and forms of deep cognitive integration that are often underrepresented in conventional assessment regimes. By proposing a spectral index linked to this state, the study expands the methodological horizon of EEG-informed educational inquiry beyond externally task-bound attention toward more introspective and self-regulatory dimensions of cognition. This is particularly important for a neuropedagogical framework that seeks to address not only visible engagement but also the internal architectures of reflection and mental orientation.

The educational utility of EEG is further reinforced by applications in intervention and regulation. Neurofeedback-based approaches represent an important extension of electrophysiological research because they transform measurement into a basis for guided self-regulation. Istiarsyah et al. (2026) report the effectiveness of neurofeedback therapy in improving behavior, emotion regulation, and attention in children with autism spectrum disorder. Although this work is positioned at the boundary between clinical intervention and educational support, it has direct neuropedagogical implications. It suggests that EEG-derived information can support not only the analysis of internal states but also their targeted modulation, thus reconfiguring the educational role of neurophysiology from descriptive monitoring to developmental scaffolding. In this respect, EEG is methodologically distinctive because it supports both observation and intervention within a common functional framework.

These advances have encouraged broader pedagogical experimentation. Elouafi et al. (2021) describe neuropedagogical methods designed to connect neuroscience findings with educational practice, while Piddubna et al. (2023) emphasize the implementation of neuropedagogical innovation in schools. Vasilieva et al. (2023) further

highlight the relationship between neuropedagogic approaches and skill formation in primary school students. Although these studies are not all EEG-centered in a narrow sense, they contribute to the rationale for using EEG within educational research by showing that pedagogical design benefits from more differentiated understandings of cognitive and affective functioning. EEG becomes particularly valuable in this context because it can provide temporal and physiological evidence regarding how learners respond to instructional conditions, thereby enriching the evidentiary basis for neuropedagogical intervention.

The expansion of EEG-informed inquiry is also linked to the digitalization of educational environments. Nefedchenko et al. (2023) discuss neuroscience-informed uses of information and communication technologies in education, while Isidori (2025) advances an AI-enhanced psychopedagogy in a performance-intensive digital domain. These developments point toward future configurations in which EEG, AI, adaptive learning systems, and psychopedagogical analytics may increasingly converge. Yet such convergence also intensifies the need for conceptual clarity regarding what EEG can and cannot validly reveal. Educational neuroscience must avoid the impression that more data automatically produce more understanding. As Paraschiv (2016) suggests in a broader reflection on information, entropy, and communication, signal generation alone does not guarantee meaning; interpretation depends on the structure of the model through which information is decoded. This insight is directly applicable to EEG research, where the distinction between signal complexity and construct validity remains fundamental.

Accordingly, psychometric rigor is indispensable. Paraschiv and Zamfirescu (2025) stress the centrality of modern psychometrics in the interpretation of complex measurement systems, and this principle extends fully to EEG-based educational research. Neural signals must be linked to clearly defined constructs, their measurement properties must be scrutinized, and their inferential limits must be explicitly acknowledged. Rad et al. (2025) offer a particularly relevant warning in their critique of measurement paradigms in affective science, showing that technologically sophisticated indicators can create an illusion of objectivity when construct boundaries remain ambiguous. In the context of EEG, this caution applies to any attempt to infer attention, engagement, emotion, or learning quality directly from oscillatory patterns without sufficient theoretical mediation and validation. The methodological strength of EEG lies in its sensitivity to neural dynamics, not in any automatic transparency of mental states.

This issue becomes even more important when EEG findings are translated into educational practice or policy. Colareza et al. (2026) argue for innovative assessment frameworks aligned with inclusion and learning progressions, and EEG-based evidence could contribute to such frameworks if used responsibly. However, the inclusion of neurophysiological data in assessment discourse also raises concerns regarding classification, standardization, and interpretive authority. Grant (2021) has shown that neuroscience-based knowledge cannot be separated from broader questions of privacy, governance, and institutional power. In educational settings, these concerns acquire special significance because learners are positioned within asymmetrical systems of evaluation and intervention. Any use of EEG in educational research or practice must therefore be justified not only methodologically, but also ethically, with careful attention to consent, proportionality, and the pedagogical purpose of data collection (Grant, 2021; Williamson et al., 2025).

Taken together, the literature indicates that EEG has become an indispensable methodological resource for investigating cognitive and emotional states relevant to learning, precisely because it captures the temporal dynamics of neural activity underlying attention, affective modulation, regulatory effort, and internally oriented cognition. Its major strengths include temporal precision, applicability across developmental and applied settings, compatibility with multimodal research designs, and potential relevance for both assessment and intervention. At the same time, its pedagogical value depends on theoretically disciplined interpretation, psychometric caution, and ethical reflexivity. EEG does not replace educational theory; rather, it enriches it by providing empirically tractable access to the neural dimension of internal learning states (Fernández, 2022; Gola, 2024; Rad et al., 2025; Friedman et al., 2026). On this basis, the next step is to synthesize the current empirical evidence more directly, in order to clarify what recent EEG studies collectively reveal about internal learning states and how these findings can support the construction of an integrated neuro-pedagogical framework.

Current EEG evidence on internal learning states

The current body of EEG-based research on internal learning states indicates an increasingly differentiated understanding of how attentional, emotional, stress-related, and regulatory processes can be examined through electrophysiological measures. Although the literature remains methodologically heterogeneous and conceptually uneven, several convergent tendencies can be identified. First, recent studies confirm that EEG is sensitive to state-dependent variations

associated with cognitive-emotional functioning. Second, the most promising contributions do not isolate neural activity from psychological interpretation, but relate oscillatory configurations to meaningful constructs such as stress, anxiety, depression, conscientiousness, and internally oriented attention. Third, the literature suggests that the pedagogical value of EEG lies less in diagnostic finality than in its capacity to enrich models of learner variability, self-regulation, and educational responsiveness (Mák et al., 2018; Piddubna et al., 2023; Friedman et al., 2026).

A first major trend concerns the growing precision with which EEG is being used to identify cognitive-emotional profiles. Adochiei et al. (2023) investigated cognitive-emotional characteristics through the method of individual asymmetries of power spectral density of EEG waves, showing that oscillatory imbalances can be approached as informative indicators of differentiated functioning. This contribution is important because it shifts attention from global, undifferentiated readings of EEG toward more refined spectral configurations capable of capturing individual variability. In the context of internal learning states, such asymmetries are particularly relevant because they may reflect differences in cognitive control, affective responsiveness, and processing style, all of which shape how learners engage with educational demands. The study therefore contributes to a more nuanced electrophysiological vocabulary for understanding learner heterogeneity, especially when cognitive and emotional dimensions are not artificially separated but examined as interdependent functional domains.

A second robust line of evidence concerns stress-related neural signatures. Adochiei et al. (2024) explored EEG patterns as indicators of stress and provided a comprehensive account of how spectral organization may be associated with psychophysiological strain. This finding is especially salient for education because stress is one of the most important modulators of learning efficiency, attentional continuity, emotional stability, and cognitive persistence. What emerges from this literature is not merely the idea that stress “affects” learning, which is already well established, but the stronger proposition that EEG can detect neurophysiological patterns associated with the internal burden under which learning takes place. This is a significant advance for neuropedagogical inquiry, since it opens the possibility of studying academic performance not only as an outcome of knowledge acquisition or strategy use, but also as a function of underlying regulatory states that may facilitate or disrupt information processing. In this sense, EEG-based stress research supports a more process-

oriented view of learning, one that foregrounds internal conditions of cognitive availability rather than external performance alone.

Closely related to stress research is the investigation of anxiety and mood-related states. Paraschiv et al. (2024), through the validation of an anxiety assessment method employing the g.TEC Unicorn Hybrid Black alongside psychological testing, demonstrate the value of combining EEG with psychometric instruments in order to avoid interpretive reductionism. The significance of this approach lies in its methodological balance: neural indicators are not treated as substitutes for psychological constructs, but as convergent sources of evidence within a multimethod framework. For state-of-the-art synthesis, this is a crucial point. The strongest studies in the field are not those that claim direct access to mental states through neural oscillations, but those that integrate electrophysiological measures with validated psychological assessments and theoretically bounded interpretations. The same logic applies to the work of Paraschiv et al. (2024) on EEG patterns related to depression, which suggests that affective dysregulation has measurable neural correlates that may be relevant for understanding diminished motivation, attentional narrowing, and reduced adaptive engagement. From an educational standpoint, these findings matter because depression and anxiety can alter the learner's internal readiness long before such effects are visible in academic output.

Another emerging tendency concerns the association between EEG patterns and dispositional or personality-related dimensions that intersect with learning behavior. Bănică et al. (2024) examined the correlation between EEG wave patterns and conscientiousness, contributing to a growing literature on the electrophysiological correlates of stable behavioral dispositions. Although such studies must be interpreted with caution, they are conceptually important because they suggest that internal learning states do not arise in a vacuum; rather, they may be shaped by more enduring tendencies related to persistence, orderliness, responsibility, and self-discipline. Conscientiousness, in particular, is relevant to educational contexts because it has been repeatedly associated with sustained effort, goal adherence, self-regulation, and academic persistence. EEG research in this area should not be taken as evidence of neural determinism, but it does indicate that dispositional structures may influence the organization of functional states during cognitive engagement. Consequently, the literature is moving toward a more layered model in which internal learning states are shaped both by situational modulation and by relatively stable learner characteristics.

A particularly innovative direction in the recent literature is the attempt to identify EEG correlates of internally oriented attention. Manea et al. (2026) propose a candidate EEG spectral index of internally oriented attention through an exploratory comparison of prayer and relaxation. Within the present review, this contribution occupies a strategic position because it extends the study of internal learning states beyond externally focused attention and reactive emotional modulation toward forms of inwardly directed cognition. This is highly relevant for educational theory, especially in relation to reflection, contemplative practices, metacognitive regulation, and the internal consolidation of meaning. Traditional educational assessment tends to privilege overt performance and task-bound responsiveness, whereas internally oriented attention involves a mode of cognitive organization that is less visible but potentially fundamental for deep learning, self-awareness, and intentional regulation. The study by Manea et al. (2026) therefore marks an important conceptual broadening of EEG-based inquiry by suggesting that electrophysiological research can also address states associated with introspection and internal cognitive alignment.

When these studies are considered together, a broader pattern becomes apparent: the field is progressively moving from coarse state distinctions toward more specific and psychologically interpretable internal-state profiles. Early EEG research in educational settings often focused on general attention, perceptual reactivity, or developmental differences, as documented in the overview provided by Mák et al. (2018). In contrast, recent work increasingly targets more differentiated constructs, including cognitive-emotional asymmetries, stress, anxiety, depressive patterns, conscientiousness, and internally oriented attention. This progression indicates a maturation of the field, not necessarily because the constructs are already fully stabilized, but because the research agenda is becoming more ambitious and conceptually elaborated. The educational relevance of this shift is substantial: rather than asking only whether learners are “engaged” or “not engaged,” EEG research is beginning to ask what kind of engagement is taking place, under what internal conditions, and with what affective-regulatory configuration.

At the same time, the literature reveals persistent methodological and interpretive constraints. One recurring challenge concerns construct validity. EEG signals are highly sensitive but semantically underdetermined; they do not map directly onto educationally meaningful categories without theoretical mediation. This issue is sharply articulated by Rad et al. (2025), who critique the illusion of measurement in affective science and warn against the reification of technologically derived indicators. Their argument is directly pertinent

to the present synthesis: the increasing sophistication of EEG analysis does not eliminate the need for conceptual clarity regarding what is actually being measured. Similarly, Paraschiv and Zamfirescu (2025) underscore the importance of modern psychometrics for validating measurement claims, a principle that applies with particular force to studies attempting to translate oscillatory patterns into constructs such as attention, emotion regulation, or inner orientation. In the absence of rigorous construct specification, EEG risks producing an excess of signal and an insufficiency of interpretive discipline.

A related issue concerns the informational status of electrophysiological data. Paraschiv (2016) argues that information and communication cannot be understood independently of the structures through which signals are organized and interpreted. Applied to EEG, this means that neural data are not inherently meaningful; their explanatory force depends on the inferential framework into which they are embedded. This observation is not merely philosophical. It has direct methodological consequences for state-of-the-art EEG research on internal learning states. Studies that combine electrophysiological indicators with psychological testing, contextual analysis, and theoretically coherent constructs are more persuasive than those relying on isolated signal features. In this respect, the recent literature shows an encouraging movement toward integrated designs, but it also indicates that the field remains vulnerable to overinterpretation when spectral patterns are treated as transparent proxies for complex mental phenomena.

The current synthesis also suggests a noteworthy convergence between EEG-based findings and broader neuropedagogical aims. Elouafi et al. (2021) describe experimental neuropedagogical methods intended to translate neuroscientific insights into educational practice, while Piddubna et al. (2023) emphasize the implementation of neuropedagogical innovation in schools. Vasilieva et al. (2023) further connect neuropedagogic approaches with the formation of primary school students' skills. Although these works are not always centered on EEG specifically, they provide an interpretive context for understanding why internal-state research matters pedagogically. The emerging EEG evidence supports the claim that learning cannot be reduced to externally observable behavior or standardized outcomes, because attentional regulation, emotional burden, and internally directed cognition significantly mediate educational performance. Consequently, electrophysiological studies of internal learning states do not stand at the margins of pedagogy; they increasingly inform the central question of how educational environments might become more responsive to neurocognitive variability.

This convergence is reinforced by broader theoretical accounts of neuropedagogy. Friedman et al. (2026) conceptualize neuropedagogy as a movement from neurons to teaching and learning, highlighting the need to connect neuroscientific evidence with pedagogical applicability. Williamson et al. (2025), however, caution that the rise of neurotechnology in education also carries risks related to governance, categorization, and the production of "learning brains" as administratively legible objects. These tensions are visible in the current EEG literature. On the one hand, electrophysiological research offers promising insights into the internal architecture of learning-related states. On the other hand, its growing pedagogical relevance increases the pressure to stabilize constructs and apply them in evaluative settings where interpretive uncertainty may be underestimated. The literature thus points simultaneously toward methodological promise and epistemic caution.

From an educational policy and assessment perspective, the synthesis aligns with the argument advanced by Colareza et al. (2026), namely that innovative assessment must be responsive to inclusion and learning progressions. EEG research on internal learning states contributes to this agenda by revealing that learners differ not only in achieved performance, but also in the psychophysiological conditions under which performance becomes possible. This is particularly important in contexts where standardized evaluation obscures the role of emotional overload, attentional fluctuation, or self-regulatory instability. The neuropedagogical significance of EEG-based evidence therefore lies in its capacity to support more differentiated educational reasoning, especially in relation to vulnerable learners, atypical developmental profiles, and contexts in which internal burdens are not readily observable through conventional pedagogical tools. In this regard, the Vygotskian-Lurian neuropsychological orientation remains highly relevant, as it frames cognitive difficulties and regulatory variation as systemic and developmentally mediated rather than as isolated deficits (Akhutina & Pylaeva, 2012).

Overall, the state of the art suggests that current EEG evidence on internal learning states can be organized around four major empirical axes: cognitive-emotional asymmetry, stress-related neural reactivity, affective dysregulation, and internally oriented attentional processes. Across these axes, the literature reveals a consistent interest in understanding how neural oscillations relate to states that are educationally consequential but often methodologically elusive. At the same time, the field remains characterized by relatively small-scale studies, construct heterogeneity, and varying levels of psychometric rigor. What is most promising is not the existence of definitive

biomarkers of learning states, but the gradual emergence of an integrative research direction in which EEG is used to refine, rather than replace, psychological and pedagogical interpretation.

The synthesis of the studies reviewed above reveals a gradual evolution in the way internal learning states are conceptualized and investigated within educational neuroscience and neuropedagogy. Early theoretical contributions emphasized neuropsychological foundations of cognitive regulation and learning processes, while subsequent research increasingly explored the feasibility of using EEG to capture attention, affective dynamics, and self-regulatory processes in educational contexts. More recent studies extend this perspective by integrating EEG-based indicators with pedagogical frameworks and classroom-relevant learning environments.

These developments suggest that neuropedagogy is progressively moving from isolated neuroscientific observations toward integrative models that link neural indicators, psychological constructs, and pedagogical practice. In order to illustrate this trajectory, Figure 1 synthesizes key milestones in the development of neuro-pedagogical frameworks informed by EEG research, highlighting the conceptual progression from neuropsychological foundations to contemporary models of EEG-informed educational research.

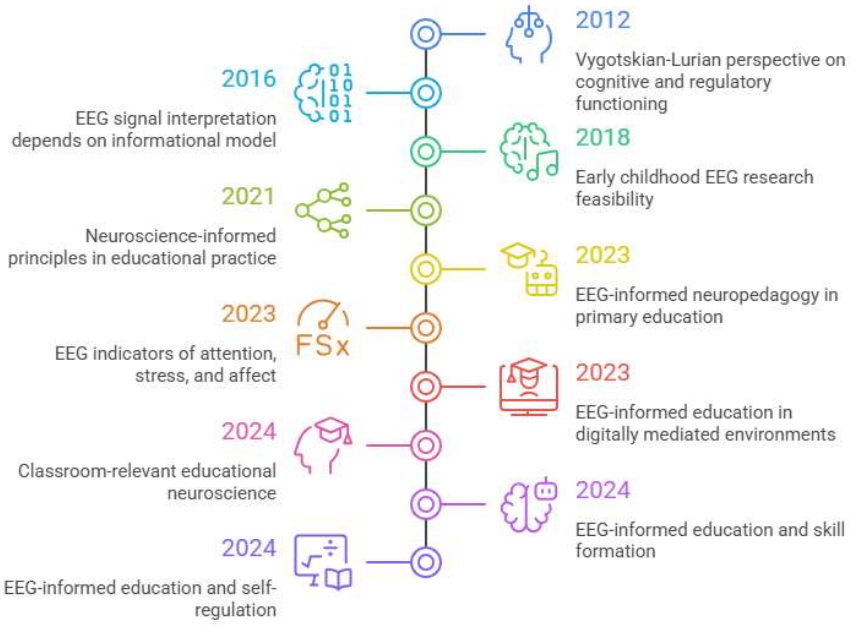

Figure 1. Evolution of neuro-pedagogical frameworks integrating EEG evidence and educational research perspectives.

Thus, the present synthesis supports three main conclusions. First, EEG research has become increasingly capable of distinguishing among multiple internal states relevant to learning, moving beyond generalized accounts of attention toward more differentiated constructs. Second, the most methodologically credible studies are those that combine electrophysiological analysis with psychological validation and theoretically bounded interpretation. Third, the literature collectively indicates that internal learning states should be treated as central mediators of educational functioning, not as ancillary variables secondary to observable performance. These conclusions create the foundation for the final step of the review: the articulation of a future-oriented neuro-pedagogical framework capable of integrating current EEG evidence into a coherent model for research, assessment, and educational practice.

Toward a neuro-pedagogical framework: future pathways for EEG-informed education

The literature reviewed across the previous sections supports the need for a neuro-pedagogical framework capable of integrating electrophysiological evidence, cognitive-affective theory, psychometric rigor, and pedagogical applicability into a coherent model of educational inquiry. Such a framework should not be conceived as a technocentric extension of neuroscience into schooling, nor as a reductive attempt to translate brain signals directly into educational decisions. Rather, it should be understood as a structured conceptual architecture through which EEG-derived information can be meaningfully related to internal learning states, interpreted through validated psychological constructs, and transformed into pedagogically relevant knowledge. In this sense, EEG-informed education requires a framework of mediation, not substitution: neural evidence should complement, refine, and sometimes challenge educational interpretation, but never replace the theoretical and contextual complexity of pedagogy itself (Friedman et al., 2026; Williamson et al., 2025).

At the core of such a framework lies the assumption that learning is mediated by internal states that are dynamic, multidimensional, and context-sensitive. Attention, emotional regulation, stress reactivity, motivational readiness, internally oriented cognition, and self-regulatory control do not operate as isolated variables; they form interacting configurations that shape the learner's capacity to engage with educational tasks. The reviewed evidence suggests that EEG can contribute to the study of these configurations by providing temporally

sensitive indicators of their neural organization. However, the educational significance of EEG does not reside in any claim to direct access to mental reality. Its value lies in the possibility of identifying functional neural patterns associated with internal states that are educationally consequential but only partially accessible through behavioral or self-report measures. A neuro-pedagogical framework must therefore begin from a layered ontology: EEG indexes neural dynamics; these neural dynamics are interpreted in relation to psychological states; and those psychological states become pedagogically relevant only within concrete instructional, developmental, and sociocultural contexts (Akhutina & Pylaeva, 2012; Friedman et al., 2026).

From this perspective, the proposed framework can be organized around three interdependent levels: the neurophysiological level, the psycho-educational level, and the pedagogical decision level. At the neurophysiological level, EEG provides indicators of oscillatory organization, spectral asymmetry, and state-dependent variation, allowing researchers to examine fluctuating neural correlates of attention, stress, affective activation, and inward orientation. Studies on cognitive-emotional asymmetries, stress-related EEG patterns, depression-linked oscillatory configurations, anxiety assessment, conscientiousness-related neural variation, and internally oriented attention collectively demonstrate that EEG can register meaningful differences in the functional organization of internal states (Adochiei et al., 2023; Adochiei et al., 2024; Paraschiv et al., 2024; Bănică et al., 2024; Paraschiv et al., 2024; Manea et al., 2026). These data, however, acquire educational meaning only when interpreted through the second level of the framework.

At the psycho-educational level, neural indicators must be translated into theoretically bounded constructs such as attentional stability, emotional burden, regulatory readiness, reflective inwardness, or cognitive-emotional disequilibrium. This level is indispensable because EEG patterns do not carry pedagogical implications independently of construct validation. Here, psychometrics and construct theory play a decisive role. The warning advanced by Rad et al. (2025) regarding the illusion of measurement in affective science is especially relevant: the apparent objectivity of neural indicators may conceal substantial ambiguity if the target construct has not been clearly delimited. Likewise, the psychometric perspective advanced by Paraschiv and Zamfirescu (2025) suggests that any EEG-informed educational model must incorporate evidence of validity, conceptual precision, and inferential transparency. A neuro-pedagogical framework should therefore resist any direct conversion of spectral features into

educational labels. Instead, it should formalize a model in which EEG contributes probabilistic and context-dependent evidence regarding internal learning states, always interpreted in conjunction with psychological theory and complementary assessment methods.

At the pedagogical decision level, the goal is not to neurologize teaching, but to enrich educational design, assessment, and intervention through a better understanding of the learner's internal conditions of engagement. In this respect, the literature on neuropedagogical implementation is particularly instructive. Experimental neuropedagogical methods have already illustrated how neuroscience-informed principles can be translated into educational practice when the emphasis is placed on adaptability, learner variability, and context-sensitive support (Elouafi et al., 2021). Similarly, the implementation of neuropedagogical innovation in schools and the relationship between neuropedagogic approaches and skill formation in primary education suggest that educational environments benefit when they become more responsive to differentiated cognitive and affective functioning (Piddubna et al., 2023; Vasilieva et al., 2023). An EEG-informed framework extends this logic by proposing that pedagogical decisions can be refined through knowledge about the internal states that mediate learning, especially in situations where observable performance offers only partial insight into the learner's functional readiness.

One of the principal future pathways for this framework concerns the development of multimethod research designs. The state of the art already indicates that the most credible EEG studies are those that combine electrophysiological measures with psychological testing, behavioral tasks, developmental interpretation, and pedagogical observation. This multimethod orientation should become a defining standard of future EEG-informed educational research. Electrophysiological indicators of stress, anxiety, or internally oriented attention gain educational legitimacy when triangulated with validated scales, contextual analysis, and meaningful learning outcomes (Paraschiv et al., 2024; Adochiei et al., 2024; Manea et al., 2026). Future research should therefore move away from mono-indicator inference and toward integrated designs capable of relating neural temporal patterns to instructional conditions, emotional experiences, and forms of learner adaptation. Such an approach would also better align educational neuroscience with the complexity of real classrooms, where internal states are shaped by interaction, feedback, environmental stressors, and task structure rather than by isolated laboratory manipulations.

A second major pathway involves the refinement of construct-specific EEG models for educationally relevant states. Current evidence suggests that attention, stress, emotional dysregulation, and inward orientation are promising domains for continued development, but the field still lacks sufficient conceptual stabilization regarding their electrophysiological signatures in educational settings. Future studies should therefore aim to define more precisely which dimensions of attention are being measured, what forms of stress are most educationally disruptive, how affective burden interacts with task engagement, and under what circumstances internally oriented attention supports rather than impedes learning. The exploratory work of Manea et al. (2026) is particularly valuable in this respect because it opens a line of inquiry into reflective and contemplative states that are central to deeper forms of learning but rarely addressed in conventional educational measurement. A robust neuro-pedagogical framework should include space for both externally task-focused and internally self-regulatory forms of cognition, thus broadening the conceptual map of what counts as educationally relevant mental activity.

A third future direction concerns developmental and inclusive applications. The literature strongly suggests that EEG-informed research may be especially useful in contexts where internal states play a critical role in learning variability, such as early childhood, neurodevelopmental conditions, emotional vulnerability, or learning difficulties. The Vygotskian-Lurian perspective remains crucial here because it conceptualizes cognitive and regulatory functioning as systemic and developmental, thereby encouraging educational models that do not pathologize learner differences but interpret them within broader functional configurations (Akhutina & Pylaeva, 2012). Early childhood EEG research has already demonstrated the feasibility of studying neurocognitive aspects of learning in young populations (Mák et al., 2018), while neurofeedback-related work with children with autism spectrum disorder indicates that electrophysiological data can also support intervention-oriented strategies aimed at improving attention and emotion regulation (Istiarsyah et al., 2026). Future EEG-informed neuropedagogy should therefore prioritize inclusive and developmental sensitivity, using neural evidence to support differentiated education rather than normative standardization.

A fourth pathway concerns the integration of EEG with digitally mediated and AI-supported educational environments. The broader literature on neuroscience in education, ICT integration, and AI-enhanced psychopedagogy indicates that future educational systems will increasingly combine cognitive modeling, digital data streams, and adaptive feedback architectures (Nefedchenko et al., 2023; Isidori,

2025). Within this emerging landscape, EEG may function as one source of high-resolution state information capable of informing adaptive learning environments, neurofeedback-supported educational tools, or reflective interfaces oriented toward self-regulation and well-being. Yet this trajectory also intensifies the need for epistemic caution. As Williamson et al. (2025) argue, the rise of neurotechnology in education risks producing learners as administratively legible neural subjects, especially when measurement systems are incorporated into governance and optimization agendas. Accordingly, any future convergence of EEG, AI, and pedagogy must remain subordinate to educational ethics, theoretical clarity, and proportional use.

This leads to a fifth pathway, namely the ethical and governance dimension of EEG-informed education. Any neuro-pedagogical framework that seeks future relevance must explicitly include principles of privacy, autonomy, informed consent, interpretive accountability, and limited inference. Grant (2021) demonstrates that neuroscience-based knowledge raises substantial legal and political questions because neural data occupy a uniquely sensitive position between the person, the institution, and the market. In educational settings, this sensitivity is amplified by age asymmetries, evaluative power structures, and the vulnerability of learners within institutional systems. Therefore, future EEG-informed education should not be guided exclusively by the question of what can be measured, but equally by the questions of what should be measured, for what purpose, under what safeguards, and with what pedagogical justification. A credible neuro-pedagogical framework must incorporate ethics not as an external add-on, but as one of its constitutive dimensions.

Another important direction concerns assessment. The emerging discussion on innovative assessment and learning progressions suggests that educational systems need more differentiated ways of understanding learner functioning, especially in contexts marked by inclusion challenges and uneven developmental trajectories (Colareza et al., 2026). EEG does not offer a replacement for assessment, nor should it be introduced as a hidden layer of neuroclassification. Its future educational value lies rather in its potential contribution to formative and research-oriented assessment models capable of identifying when poor performance may reflect internal-state constraints rather than lack of competence or effort. For example, attentional instability, excessive stress, or affective burden may compromise task performance without reflecting the actual developmental potential of the learner. A neuro-pedagogical framework informed by EEG could thus support more context-aware

interpretations of educational outcomes, especially when combined with observational, psychometric, and curricular evidence.

Methodologically, future research should also prioritize replicability, construct coherence, and ecological validity. Many existing EEG studies remain exploratory, small-scale, or context-limited, which is understandable in an emerging interdisciplinary field but insufficient for broader pedagogical generalization. Future investigations should therefore include larger samples, clearer task paradigms, stronger multimodal validation, and designs that better approximate educational reality. Classroom-compatible EEG paradigms, ecologically valid cognitive tasks, and longitudinal studies linking internal states to actual learning trajectories would be particularly valuable. Equally important is the need to improve theoretical alignment between electrophysiological findings and educational concepts. As Paraschiv (2016) reminds us, signal interpretation always depends on the informational model within which the signal is embedded. Future EEG-informed education must therefore avoid data accumulation without conceptual architecture; it requires models in which neural patterns, psychological constructs, and educational processes are systematically aligned.

At a broader level, the proposed framework also invites a reconceptualization of pedagogy itself. Neuropedagogy does not imply that teaching should become neuroscientific in form, but that pedagogy may benefit from a more explicit recognition of the internal architectures that condition learning. Gola (2024) emphasizes the classroom relevance of educational neuroscience, while Friedman et al. (2026) frame neuropedagogy as a movement from neuronal understanding to teaching and learning. Building on these perspectives, EEG-informed education can be understood as a future-oriented pedagogical paradigm in which instructional design, learner support, and educational assessment become increasingly sensitive to the temporal dynamics of attention, affect, regulation, and internal orientation. This does not diminish the role of culture, dialogue, curriculum, or teacher judgment; on the contrary, it deepens pedagogical reasoning by situating learning within a more comprehensive model of human functioning.

In conclusion, a future-oriented neuro-pedagogical framework for EEG-informed education should rest on several core principles: theoretical non-reductionism, construct-valid interpretation, multimethod integration, developmental and inclusive sensitivity, ethical accountability, and pedagogical relevance. EEG can play a valuable role in this framework because it offers access to the neural temporality of internal learning states, but its contribution becomes

meaningful only when embedded within psychologically coherent and educationally justified models. The literature reviewed in this paper suggests that the field is now ready to move beyond isolated proof-of-concept studies toward a more integrated research program in which EEG is used to clarify the internal conditions of learning, refine educational interpretation, and support more responsive pedagogical practices. In this sense, the future of EEG-informed education does not lie in the search for simplistic neural markers of learning success, but in the construction of a disciplined and conceptually mature neuropedagogy capable of linking brain dynamics, internal states, and educational action into a coherent scientific framework.

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