Educational Neuroscience in the Classroom

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By

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TABLE OF CONTENTS

LIST OF FIGURES
(SEE CENTREFOLD FOR FIGURES 1, 2, 4 AND 5 IN COLOUR)

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PREFACE

PROF. MICHAEL S.C. THOMAS

It was indeed a great honour to be asked to provide an introduction to Professor Gola's book – Educational Neuroscience in the Classroom. In this captivating work, he delves into the intricate connection between neural networks and teaching, exploring the interplay between neuronal pathways and the instructional and pedagogical methods employed by both teachers and students.

Educators have sometimes hesitated to integrate the science of the brain into teaching, fearing it might oversimplify the complex social and cultural dimensions of education. In " Educational Neuroscience in the Classroom" however, Professor Gola confronts this hesitation, referencing authors like Williams and Standish (2018), who question the relevance of neuroscience to education. While it's clear that reducing education to mere neural activity overlooks its cultural and social aspects, acknowledging the biological foundations of the brain is essential.

An understanding of how the processes of learning operate, and occasionally falter, can profoundly enhance teaching practices. Thus, disregarding the brain's significance is both shortsighted and illogical. Proof of this can be observed in the advancements we see in artificial intelligence and robotics, which highlight the diverse ways cognitive systems can in principle operate and learn, as well as how bodies can be controlled. However, the unique characteristics of the human mind stem from its biological basis.

Let's consider the following: As individuals, we frequently forget rarely used knowledge or names, such as the capital of Bolivia or who the president of Ghana is, but we rarely forget information like our phobias or favourite meals. This phenomenon suggests that our memory prioritises certain types of information over others. Also, the struggle to grasp very novel facts, like quantum theory, contrasts sharply with how easily we recall novel personal experiences, such as memorable encounters. What do you think causes this difference in retention? Is it related to how our brains process abstract concepts versus concrete events?

Computers demonstrate that, in theory, facts, events, and fears could all be learned and retained indefinitely. However, our minds function the way they do due to the intricate workings of our brains. Different types of knowledge engage different brain systems, each with its own learning and forgetting properties. This insight is invaluable for educators, as it sheds light on how to optimise teaching strategies.

Educational neuroscience is part of a broader movement advocating for an evidence-informed approach to education. A recent UNESCO report by the Mahatma Gandhi Institute of Education for Peace and Sustainable Development (MGIEP; https://mgiep.unesco.org/iseeareport) aimed to undertake a scientifically robust and evidence-based assessment to inform education policy-making at all levels and scales. The report contributed to UNESCO's ambition to re-envision the future of education (https://www.unesco.org/en/futures-education). The MGIEP report identified the goal of education as supporting human flourishing and emphasised the importance of adopting a whole-brain, learner-centric approach to learning that strengthens the interconnectedness of cognition and the social-emotional domains.

The million-dollar question (or perhaps now billion-dollar) is: How can we effectively translate insightful ideas about how the brain learns into practical guidelines for teachers, supporting them in their practice? How can neuroscience assist educators while promoting their autonomy and flexibility within the dynamic educational and social contexts of the classroom? As Professor Gola emphasises in his book, "It remains challenging for teachers to access useful and pertinent neuroeducational information that can be translated into actionable teaching practices." However, this does not imply that neuroscience insights cannot enhance teaching practices. On the contrary, according to this book, there are several ways in which neuroscience can aid educators and learners. Firstly, educators will gain knowledge beyond mere cognition, incorporating embodiment and sensorimotor skills, thereby enriching the psychology of learning. Additionally, they will understand the importance of rewards, emotions, and social context.

It will also assist by emphasising the brain as a biological organ with metabolic needs. This perspective will inform insights into brain health and the effects of factors such as sleep, diet, stress, and fitness on learning. Additionally, teachers will learn to recognize that their emotional approach to teaching content (whether it's anxiety or curiosity) can be sensed by students and affect their learning. Similarly, students will understand the changes in their brains during adolescence, such as shifts in circadian rhythms leading to later sleep patterns, and the increasing influence of peer approval as a motivating factor. In essence, neuroscience will empower both teachers and learners to take agency in their educational journeys.

It is important to acknowledge that while neuroscience can be beneficial to educators in teaching practices, it isn't always applicable. Merely substituting established psychological concepts like attention with neuroanatomical terms, such as the fronto-parietal network, doesn't necessarily enhance understanding. Neuroscience findings must be effectively communicated to prevent misconceptions or "neuromyths," like the idea that we only use 10% of our brains or that there are distinct left-brain and right-brain thinkers, both of which have been debunked a myths. We should be cautious of "neuromania" and avoid overstating the capabilities of brain sciences. Ultimately, neuroscience can serve educators, but it shouldn't be elevated to a higher status than that.

I leave you with the thought-provoking perspective offered by Professor Gola: that teachers act as neural sculptors, akin to mental neurosurgeons, entrusted with the shaping of minds. Enjoy delving into this volume and exploring the transformative journey it unveils!

Prof. Michael S. C. Thomas
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INTRODUCTION

You are nothing but a pack of neurons.

In 1994, renowned biologist, geneticist, and Nobel Prize laureate Francis Crick made the now renowned and controversial statement: "You are nothing but a pack of neurons" (1994, 3). This reflects a certain perspective in science, where the more vivid and evocative the data is, the more recognisable it appears to be, shaping our understanding of reality. McCulloch previously argued in 1946 (cited 1965) how ideas are embodied in networks of neurons.

In Poldrack's well-known text "The New Mind Readers: What Neuroimaging Data Can and Cannot Reveal About Our Thoughts" (2018), he highlights the substantial yet inferential relationship between the signals picked up, the data collected and the conclusions supporting scientific reasoning about the brain.

In today's scientific community, the claim of neuroscience to be the "true" science of the mind and brain, often inferred from new brain-imaging techniques, provides evidence for the cognitive identity of the mind and brain. However, doubts persist: experimental results reveal levels of interaction between brain areas and elements of good neural health, indicating brain functionality. Yet, some dimensions remain unclear, prompting scholars to delve into these principles over time.

One such dimension revolves around understanding how thoughts are generated, knowledge is gained, and how people learn—these are the questions that intersect frequently with pedagogy and learning. According to the prevailing view, neuroscientists attribute thinking, reasoning, computing, believing, fearing, and hoping to the brain. However, as Hacker (2012) suggests, in reality, it is human beings who do all these things, not their brains. So, in a complex of neurobiological experiences and relationships, why would the brain be of educational interest?

If we view this from a positivist perspective, this question seems straightforward; however, in today's education studies, interest in the human brain is met with scepticism (Williams & Standish, 2016). On the pedagogical front, positions on the topic garner both widespread support and significant disagreement. The integration of neuroscience into educational research creates a space for contention. While some researchers argue that discussing educational phenomena through neuroscience is impossible and will never be feasible, others seem more optimistic, believing it is achievable under certain conditions (De Smedt, 2018).

Neuroscience plays a growing role in education, informing pedagogical practices. However, it's crucial to avoid overreliance on a "neurocentric" approach that prioritises specific findings over the complexities of learning and brain development. Our understanding of both is constantly evolving, and educators should approach neuroscientific insights with a critical lens. Recognising the ongoing dialogue and continuous refinement in this field is essential. The intersection of neuroscience and education offers opportunities to enhance teaching practices and improve learning outcomes. However, it's essential to acknowledge the limitations and complexities involved. John Bruer's seminal work "Education and the Brain: A Bridge Too Far" highlighted the gap between neuroscience and education, sparking ongoing debates about the relevance of neuroscience to educational practices.

Collaborative efforts between neuroscientists, educators, and researchers can facilitate meaningful integration and application of neuroscientific principles in educational contexts.

For instance, if cognitive psychology research suggests that multisensory experiences (visual, auditory, tactile) benefit learning, does knowing which brain regions are involved truly enhance our understanding? Or does including such information merely add a superficial appeal, making the results appear more impressive? The debate is not new.

Neuroscience may have garnered significant attention and broadened our understanding of the brain, but its fundamental research methods have been criticised for their overreliance on reductionist frameworks and deterministic interpretations. These approaches, while valuable in certain contexts, may not fully translate to the complexities of educational settings.

Scholars caution against overly reductionist viewpoints, arguing that attributing specific functions solely to isolated brain regions can create a misleading oversimplification, akin to the "meteorological fallacy." This fallacy refers to the mistaken assumption that a single weather event can represent the entirety of a climate system. Similarly, attributing complex cognitive processes solely to specific brain regions can overlook the intricate interplay between various brain areas and environmental factors that influence learning.

By acknowledging the limitations of reductionist approaches and embracing a more holistic perspective, neuroscience can offer valuable insights that inform and enhance educational practices. Others suggest that despite the fervour in neuroscientific research, its actual contributions to education remain unclear, often falling short of expectations.

Educational neuroscience bridges the gap between brain research and education. This emerging field combines insights from various disciplines, including cognitive science, psychology, technology, and education theory. It aims to understand how the brain learns and how these insights can inform teaching practices.

While educational neuroscience is still gaining recognition, it emphasises a collaborative approach that integrates knowledge from different fields to improve learning outcomes.

While it is a promising field, its practical applications are still being developed. Theories in this field often overlap, however, translating them into effective teaching methods remains a challenge.

Neurodidactics, which applies brain research to education, goes beyond studying the brain itself. It also considers factors like motor skills, perception, and sensory functions. This broader approach provides valuable tools for understanding and improving teaching and learning, paving the way for innovative educational practices.

While some areas of neurocognitive science hold promise for education, they have yet to be widely adopted in educational settings. One such area is research on brain oscillation synchrony, which examines the brain's electrical activity in response to stimuli.

This research delves into the connection between the brain's networks, the physical body, and how these elements influence teaching and learning. It specifically explores the relationship between neural networks, teacher explanations, and student learning. The goal is to analyse this connection and propose potential contributions to educational practices.

At a time when educational neuroscience was gaining widespread acceptance (Battro, Dehaene, Singer, 2011) and contributing to a refined scientific discourse, researchers were getting closer to understanding the deeper meanings behind teaching and the hidden aspects of knowledge and serious efforts were made to unravel the complexities of teaching and learning. At that time, examinations kept neuroscientific rationales separate from educational implications, but a new framework emerged that integrated neurocognitive, bioeducational, and introspective perspectives. This framework would eventually lead to internationally recognised propositions and numerous confirmatory studies. Initiatives such as the OECD's Brain and Learning project, the International Mind, Brain, and Education Society, Mind Brain Education, Neuroeducation, and Educational Neuroscience represent just a few examples and variations (refer to Chapter I).

The questions that oriented that kind of research were, in some ways, close to the pages that follow, where we will delve deeper into the established yet critical meanings of teaching, specifically from the perspective of neuroscientific epistemologies of knowledge. Our goal is to identify practical elements applicable to teaching practices that are valuable for educators. This aligns with the concept of evidence-based practice in educational science, aiming to develop knowledge that is both scientifically sound and adaptable to different contexts (Matta, 2021). The risk of an ontology of mental or cognitive prevalence is widely present.

The text also addresses scepticism surrounding the application of neuroscience to education (Joldersma et al., 2016; Beale, 2021). This scepticism often stems from misinterpretations of complex research or overly simplistic applications. Some educators may seek quick fixes based on superficial readings, while others reject the field entirely.

The act of teaching is intrinsically linked to learning, the students and teachers involved, and the environment where it unfolds. Pedagogical and didactic science provide a theoretical and practical framework for understanding this process. This knowledge is constantly evolving and requires a scientific research approach. Neuroscience offers valuable insights into teaching and learning, but it's crucial to avoid oversimplifications. This initial examination explores some fundamental concepts through the lens of neuroscience, aiming to bridge the gap between theory and practice in educational neuroscience.

This book is divided into five chapters. The first two chapters delve into the theoretical foundations of educational neuroscience, with a particular focus on the recent shift towards research in real-world environments. This shift moves beyond laboratory settings to examine neural correlates of learning in authentic contexts, encompassing the knowledge gained through experience and situation.

The following chapters (III and IV) explore practical applications of educational neuroscience based on the findings of Model-Based Encoding (MBE) research, which will be introduced within the Teaching Brain framework.

Chapter V explores two complex and evolving areas. First, it examines ethical considerations in educational neuroscience research, a topic gaining increasing scientific attention (paragraph 5.1). Second, it delves into theoretical attempts to move beyond a purely neuroscientific perspective on learning (paragraph 5.2). This section emphasises the importance of paradigmatic freedom, a flexible approach that contrasts with the rigid metrics often favoured in cognitive neuroscience.

The chapter then highlights the brain's plasticity and its ability to continuously adapt and learn from experiences (paragraphs 5.3, 5.4). This concept is linked to the idea of "epigenesis of co-knowledge," which suggests that learning is a non-linear process shaped by both biological factors and educational interactions. Siegel's (1999) perspective on the mind is also introduced, emphasising the interplay between interpersonal experiences, the brain, and the whole organism.

The book explores the concept of the teacher as a "neural sculptor," responsible for shaping the minds of their students (Margiotta, 2007). This metaphor, however, might be overreaching current capabilities in educational neuroscience. Nevertheless, the book seeks to identify some fundamental principles of how neuroscience can inform our understanding of knowledge acquisition.

I. Theoretical Framework

CHAPTER I

NEURO UMBRELLA

Mind Brain Education: Transdisciplinary Perspective

Neuroscience research has been influencing (at various levels) our educational theories and practices[1] for nearly four decades. This body of research, often referred to as the "neuro-umbrella", explores various educational phenomena through the lens of the brain.

Scientific paradigms are foundational to any scientific endeavour. They offer a framework that promotes coherence, clarity, and a linear progression of knowledge within a specific field. This structured approach ensures consistency and facilitates communication among researchers. However, there's an inherent risk associated with paradigms: they can become so ingrained that they restrict exploration outside established boundaries. In the pursuit of new knowledge, a paradigm can morph into a dogmatic limitation, hindering groundbreaking discoveries.

The recent advancements in neuroscience are a compelling example. This field offers an invaluable lens through which we can examine the complex relationship between the mind and the brain (Salerno, 2015). Neuroscience research has the potential to revolutionise our understanding of learning, memory, and human behaviour. Yet, it's crucial to avoid creating an overly rigid hierarchy within the vast landscape of knowledge related to the brain. An inflexible hierarchy could restrict researchers from exploring alternative explanations and integrating insights from other disciplines. By maintaining a balance between established paradigms and the freedom to explore new avenues, we can ensure that neuroscience continues to contribute significantly to our understanding of the human mind and brain.

The field of neuroscience appears to be entering a new and exciting era of collaboration. By overcoming differences in epistemology, methodology, or the perceived divide between theory and empirical research (Sander,

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[1] Examples include the works of: Berninger, Abbott, 1992; Iran-Nejad, Hidi and Wittrock, 1992; Jensen, 2005; Willingham, Llyod, 2007; Schwartz, 2015. In Bibliography.

2021), researchers can achieve much more together. This collaborative approach is central to the concept of Mind, Brain, Education (MBE[2]).

The multifaceted challenges in education and instruction demand a nuanced approach. We need to understand and improve learning and teaching processes by examining them through multiple lenses. The Mind, Brain, Education (MBE) framework is a product of this ongoing scientific exploration. While still evolving, MBE offers a valuable framework for integrating insights from neuroscience, psychology, and education. This collaborative approach fosters a deeper understanding of how we learn and how we can best teach.

While questions about the brain and mind differ from those in education, a rich overlap emerges when we consider the intersection of various disciplines. As Tokuhama-Espinosa (2011, 2019) clarifies, Mind, Brain, Education (MBE) is an interdisciplinary science that bridges cognitive neuroscience, developmental psychology, and education (particularly educational psychology). This integration necessitates grappling with the distinct paradigms, methods, and epistemologies (fundamental beliefs about knowledge) that each discipline historically brings to the table. As Samuels (2009) and Mariani (2016) point out, these disciplines have their own scientific and social influences and considerations. MBE's strength lies in its ability to bridge these divides and foster a more comprehensive understanding of learning and teaching.

The early 2000s saw a surge in the influence of cognitive neuroscience on education, with the hope that it would inform educational psychology (Geake, 2005, 2009). However, it became clear that cognitive neuroscience alone was insufficient. Today, the Mind, Brain, Education (MBE) approach offers a more comprehensive framework. MBE recognises that educational issues are multifaceted and require insights from various disciplines. Through translational research, MBE seeks to bridge the gap between scientific disciplines and educational practice. This cross-disciplinary approach fosters a deeper understanding of learning and teaching, with the goal of generating more complete solutions informed by multiple scientific perspectives (Tokuhama-Espinosa, 2011, 2019). This shift represents a fundamental change in how we view teaching and learning. It's both a paradigm shift, meaning a change in underlying assumptions, and an epistemological shift, meaning a change in how we understand and acquire knowledge. In this new framework, education is no longer simply informed by neuroscience and psychology, but rather stands as an equal partner (Tokuhama-Espinosa, 2011). All three disciplines (neuroscience,

[2] For an in-depth discussion of the historical evolution of the MBE, see the contribution of Nouri, Tokuhama-Espinosa, Borja, 2023, especially appendix D.

psychology, and education) contribute their unique expertise, leading to a more comprehensive and constantly evolving understanding of learning and teaching.

Bruer's concept of a bridge emphasises a two-way flow of knowledge, not just from neuroscience to education and psychology, but also vice versa. This cyclical and non-linear exchange fosters a new epistemological framework. Within this framework, the more traditionally confirmatory metrics of neuroscience must converge with the more open-ended methods of educational science. This creates a need for neuroeducation to embrace a dialogical (Albanese, 2022) and interdisciplinary/transdisciplinary character (Feiler, Stabio, 2018; Nouri, Tokuhama-Espinosa, Borja 2023), which can be challenging to achieve.

Building on this idea, Frauenfelder and Santoianni (2002, 2004) proposed the Bio-Educational Sciences paradigm. This framework emphasises a transdisciplinary approach to research, drawing not just from neuroscience but also from biology and education. Their concept of "bio-pedagogy" highlights the intersection of these fields, aiming to create a more comprehensive understanding of learning and teaching.

The concept of transdisciplinary research is gaining traction in international scientific circles. As Santoianni (2019) emphasises, this approach doesn't require individual disciplines to abandon their unique epistemologies (ways of knowing). Collaboration and the exchange of ideas don't necessitate the loss of disciplinary distinctiveness. In essence, neuroscience, education, biology, and cognitive science can all maintain their rigorous epistemological frameworks while interacting to explore the mind and brain's role in learning and teaching (Gola, 2020). This collaborative approach fosters new and potentially challenging contributions to the field, with each discipline enriching the other through shared areas of knowledge construction.

Concerns linger about the ability of "neurodidactic" research to directly translate to practical teaching strategies. This highlights the need for ongoing reflection on how these findings can be applied in educational settings. Thankfully, the dialogue between education, psychology, and neuroscience is flourishing. Masson Borst (2017) suggests 1999 as a pivotal year for neuroeducation research, marking the launch of a large-scale OECD inquiry into the impact of neuroscience on education. However, the groundwork was laid much earlier, with the evolution of educational neuropsychology studies and research programs at universities. The past two decades have witnessed a surge in international collaboration, with leading scientific societies like the International Mind, Brain and Education Society (IMBES) and the Mind, Brain, and Behavior Society playing a key role. Additionally, special interest groups like the American Educational Research Association's Brain, Neurosciences, and Education group and the European Association for Research on Learning and Instruction's Neuroscience and Education group have fostered further collaboration. Harvard University's Mind, Brain, and Education program exemplifies this international movement.

Despite gaining recognition, neuroeducation requires ongoing research and diverse scientific contributions (Albanese, Compagno, 2021; D'Alessio, 2019). This field has the potential to address educational challenges and social emergencies (Santoianni, 2018).

Summak et al. (2010) highlight the promise of neuroscience in supporting education. By understanding the neurological basis of learning and recognising individual neurological variations, we can develop more appropriate teaching styles and learning programs. Additionally, neuroscience can inform the design of effective interventions for students with learning difficulties (Gola, 2020).

Recent research explores the practical implications of neuroscience for teaching, often called "Brain-Based Learning" (Willingham, Llyod, 2007). This approach emphasises using neuroscientific findings to improve teaching practices and support learning.

Neuroscience offers valuable insights that can influence education in numerous ways. These include:

- How environmental and cultural factors influence brain development through synaptic changes (Rivoltella, 2012).
- The role of modelling, imitation, repetition, and prediction in cognitive processes.
- The impact of acquiring instrumental skills on brain structure (D'Alessio, 2019).
- The connection between emotions, social interaction, and learning (Immordino-Yang, 2016).
- The importance of sensory function in facilitating adaptation and learning (Olivieri, 2014).
- The link between movement and cognitive development.

However, there's much to learn. Integrating neuroscience with educational expertise is crucial for developing more effective teaching methods.

Neuroscience research can also inform educational policymakers and teachers. It's important to translate complex scientific jargon into practical terms for educators (Banich, Compton, 2018). A key challenge lies in bridging the knowledge gap between neuroscientists, teachers, and educational researchers. While scientists possess specialised research knowledge, teachers have a deep understanding of classroom realities and the broader societal role of education.

An Open Debate: Neuroscience, Neurocognition, Education

The past two decades have seen a surge in brain research, leading to the emergence of new academic fields in education. These fields share some overlap but have distinct nuances and theoretical approaches. In the English-speaking world, "Neuroeducation" is more common, while North America often uses "Mind, Brain, and Education." Tokuhama-Espinosa (2019) argues that effective teaching requires not only subject-matter knowledge and pedagogical skills but also familiarity with the "learning sciences," which combine insights from education, psychology, and neuroscience. Here's a breakdown of some key terms:

- Educational Neuroscience (Thomas et al., 2020): This field focuses on the brain's role in learning and educational processes.
- Mind, Brain, and Education (Fisher, 2009): This is a transdisciplinary space that integrates insights from neuroscience, psychology, and education. Each discipline retains its unique perspective.
- Neuroeducation (Battro et al., 2008): This is a broader term encompassing the study of the brain's relation to education.
- Neuropedagogy (Houdé, 2006): This field focuses on applying neuroscientific findings to develop teaching practices.
- Brain-Based Learning (McBrien & Brandt, 1997): This approach emphasises using neuroscience research to improve teaching and learning.
- Brain Education Cognition (Santoianni, 2019): This term highlights the intersection of brain research, education, and cognition.

The learning sciences aim to understand how people learn most effectively under different conditions (Sawyer, 2005). This broad field encompasses various disciplines that share common challenges related to knowledge acquisition, including neuroscience, cognitive and learning psychology, education, and didactics (Fischer et al., 2018). These disciplines can inform each other through independent research and collaborative efforts.

However, concerns have been raised about the practical application of educational neuroscience in classrooms. Bowers (2016) criticises the lack of direct evidence linking neuroscience research to improved teaching practices. He argues that some claims about the impact of educational neuroscience are overstated, and emphasises that core educational outcomes are often behavioural, such as reading or maths proficiency. Gabrieli (2016) identifies three main weaknesses in Bowers'analysis, which we shall discuss.

Educational Neuroscience: Potential and Promise

Educational neuroscience offers a unique perspective on learning, but it's crucial to understand its role. While it's a foundational science that informs educational research, it doesn't provide direct classroom instructions (Bowers, 2016). However, its findings can influence educational practices and policies beyond curriculum development, especially when addressing the needs of disadvantaged students (Gabrieli, 2016).

Brain imaging studies in educational neuroscience have shed light on the connection between brain activity and learning outcomes. These studies not only reveal the neurological basis of learning difficulties but also identify individual brain variations that influence how effectively students learn (e.g., predicting which students might benefit most from specific interventions). In some cases, brain-based measures have proven more accurate than traditional behavioural measures in predicting individual learning success. These results suggest that educational neuroscience can contribute to personalised and more effective education.

The Evolving Landscape of Neuroeducation

As mentioned earlier, the terms "neuroeducation" and "neuroteaching" are often used interchangeably. The field itself has roots in neurobiology and neuropsychology, but it has blossomed into a broader area encompassing various disciplines (Piazza & Pavani, 2022). This crossroads of knowledge brings together brain function, cognition (the nature, structure, and formation of knowledge), behaviour, and education.

Terminology and a Multifaceted Approach

The terms "neuroeducation" and "neuropedagogy" emphasise the educational aspect, while "educational neuroscience" prioritises the neuroscience component. To bridge this divide, Battro et al. (2008)

proposed using "Mind, Brain, Education" to highlight the field's multifaceted nature (Masson & Borst, 2017).

Tokuhama-Espinosa (2015, 2019a) further emphasises an integrated perspective, suggesting a specific approach (epistemology) for neuroeducation. This approach emphasises the convergence of mind, brain, and education. At its core are various disciplines – neuroscience, education, and psychology (Thomas et al., 2019) – with additional contributions from philosophy, linguistics, anthropology, sociology, ethnology, and biology.

By fostering collaboration across these disciplines, educational neuroscience holds the potential to revolutionise how we understand and support learning for all students.

In continuity with the international contributions above, the field of educational neuroscience has emerged from a confluence of various research areas. Early contributors like Frauenfelder (1983, 2002, 2003) laid the groundwork with the concept of bio-educational research, emphasising the synergy between biology and education. This perspective later evolved into the more precise “Brain Education Cognition” framework, solidifying the theoretical foundation for neuroeducational and neurodidactic research.

Around the same time, Rivoltella's work (2012) further fueled the discussion, pioneering research in what he termed "neuroeducation" (see Ch. III). This growing interest in the intersection of biology and education reflects a two-decade-long trend of "cross-looking" between neuroscience and educational practices.

Neuroscience has the potential to benefit both educators and students. By understanding the brain's learning processes, teachers can develop more effective teaching methods (Rojas et al., 2022). Students, in turn, can learn how to optimise their learning experience within the educational environment.

However, further research is needed to fully translate the potential of brain imaging and other neuroscientific methods into practical applications. The ideal approach involves combining neuroscientific insights with behavioural, pedagogical, and educational studies. This collaborative effort aims to identify teaching styles that foster meaningful learning, ultimately nurturing critical thinkers equipped to solve the challenges of our times (Rojas et al., 2022).

Educational neuroscience explores how insights from neuroscience can be applied to improve teaching and learning. The goal is to develop effective strategies that leverage how the brain learns (Tham et al., 2019).

This field, also known as neuroeducation, has broadened our understanding of knowledge acquisition. It focuses on both the learner and the educator, emphasising how teaching styles can optimise learning

(Battro, 2007, 2010)[3]. This approach encompasses the entire learning process, from instruction and delivery to student understanding and cognitive development.

One key takeaway from neuroeducation is the evidence-based principle of active learning. The brain thrives on engagement and plasticity (the ability to adapt and change). Research now shows that experiences, education, culture, and perceptions can influence brain structure and gene expression, not just the other way around (Rueda, 2020). In other words, learning shapes the brain as much as the brain shapes learning.

Limits and Opportunities of Neuroscience for Education

While cognitive science holds promise for improving education, some argue that its current explanatory approach may not be sufficient (Minello, 2011). Effective learning likely involves a continuous cycle of experience, prediction updates, and assumption revisions throughout life, shaping the brain's neural architecture (plasticity).

However, the idea that neuroscience can inform education remains controversial. The rapid growth of educational neuroscience has exposed misconceptions – neuromyths – about the brain (Geake, 2009; Sousa, 2010; Tokuhama-Espinosa, 2010; Pasquinelli, 2012; Smeyers, 2016b; Sander et al., 2018; Tardif, 2020; Ulusoy et al., 2023). These include ideas like strict brain lateralization, learning limited to critical periods, or specific learning styles linked to brain function.

Neuromyths[4], often oversimplifications of scientific findings, can mislead educators and create a rift between scepticism and overenthusiasm.

Furthermore, critics argue that neuroscience may not be able to significantly influence educational practices or provide frameworks for knowledge construction and pedagogy (Gola, 2021 a; b; c).

Some argue that neuroscience can only offer photographs of the mind, even if the evidence is strong. This debate is aptly captured by the term coined by Della Chiesa. Some scholars argue that educational neuroscience has limitations. Meirieu (2018) contends that neuroscience can't capture the subjective experiences of students in classrooms, including their individual thought processes. While new brain imaging techniques can provide detailed information about brain activity during learning, they don't

[3] On the subject see bibliography; however, the main works of: Strauss, 2005; Fisher, 2009; Fisher, Daniel, 2009; Fisher et al., 2007; Goswami, 2004, Geake, 2009; Hinton, Fisher, 2008; Busso, Pollack, 2014; Immordino-Yang, 2013; Tibke, 2019.

[4] The term Neuromyths was first coined by neurosurgeon Alan Crockard in the 1980s to describe unscientific ideas about the brain in medical culture.

necessarily translate into practical changes in classroom content, teacher-student relationships, or the meaning-making process of learning.

This critique resonates with others (Cuthbert, 2015; Bowers, 2016; Krammer et al., 2021; Joldersma et al., 2018). They point out that misconceptions[5] about the brain can hinder research and its application in educational settings (Dekker et al., 2012; Geake, 2008; Goswani, 2006; Santoianni, 2019).

Cambi (2011) further questions the dominance of neuroscience in education. He argues that brain research shouldn't be seen as the sole explanation for complex human experiences that are shaped by existential, cultural, and historical factors. This "neuroscientific imperialism," as he calls it, risks oversimplifying the issue.

An alternative perspective, championed by Cambi (2011), emphasises the importance of interpretation. This approach focuses on how individuals make sense of experiences within a specific context, considering factors like language, mental categories, and personal background.

Education, by its nature, involves a constant interplay of ideas and experiences. Therefore, the relationship between education and neuroscience needs to be critical and multifaceted. Educational practices can benefit from data from neuroscience, but it's crucial to integrate this data with other fields and consider the different levels of reality at play.

While the neurobiological approach has shed light on learning processes, it doesn't fully explain how the brain's physical structure gives rise to conscious and unconscious mental phenomena (Minerva, 2018).

Despite some scepticism and concerns about reductionism, recent discussions highlight the importance of considering multiple perspectives – neuroscience, education, and knowledge itself – when looking to improve educational practices.

Even with this troubled scenario, there's recognition that knowledge of brain function can contribute to understanding teaching and learning. A deeper understanding of how to promote and sustain neuronal connections can facilitate learning processes.

As Bruer (1997) observed, interest in neuroscience's role in education has grown significantly. The appeal lies in the potential for neuroscience to resolve educational controversies by providing objective brain data, considered less ambiguous than behavioural data (Sander et al., 2021).

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[5] Misinterpretations of neuroimaging research [one of the possible neuroscientific methods] occur in several ways: distortion of results by scientists or the media to kindle interest, commercial interests, or poor public involvement by researchers. Biased communication of neuroimaging capabilities generates distrust or unrealistic or unfounded expectations about the fallout (Wardlaw et al. 2011).

Many scholars, including Geake (2009), Goswani (2004, 2006), Jensen (2008), Rivoltella (2012), and Oliviero (2014, 2016), advocate for using neuroscience research to inform teaching practices. They envision a collaborative effort where educators help define research priorities and translate scientific findings from cognitive and neurological sciences into classroom applications (Ansari & Coch, 2006).

This focus on bridging disciplines and applying research findings is central to the ongoing debate on educational neuroscience. It's also likely a reason for the continued divergence of opinions (Matta, 2021; Feiler & Stabio, 2018).

A central question in the debate surrounding educational neuroscience is its effectiveness (Cuthbert, 2014). Some argue that its focus on brain function clashes with the core values of liberal and humanist education, which emphasise freedom and critical thinking (Arendt, 1993; Bailey, 2009; Furedi, 2009; Hirst, 1965; Peter, 2007; Oakeshott, 1971; Turner, 2012).

For a successful implementation of educational neuroscience, it's crucial to consider both epistemology (the nature of knowledge) and ethics. Educators require freedom to develop their methods based on disciplinary knowledge and their own professional judgement. Excessive reliance on prescriptive methods derived from neuroscience could stifle this essential freedom.

Furthermore, there's a concern that educational interventions based solely on neuroscience might overlook other explanations for learning processes. The dominance of neuroscientific language in educational research can be problematic (Viola, 2023).

Despite these concerns, there's an ongoing effort to bridge the gap between scientific research and practical applications in education (Churches et al., 2017, 2020; Wilcox et al., 2021). Collaboration between neuroscientists, educators, and teachers holds promise for developing more effective educational approaches.

Recent discoveries in neuroscience and neurocognition are prompting new ways of thinking about how knowledge is formed in the brain. These models emphasise the concept of "knowledge-generating neural networks" shaped by individual experiences.

Brain imaging techniques have revealed correlations between specific patterns of brain activity and certain behaviours. A well-known example is the link between the prefrontal cortex (involved in planning and decision-making) and executive function (Bell & Darlington, 2020).

The view of cognitive functions residing in isolated brain regions is no longer dominant. Current understanding suggests that these functions arise from the coordinated activity of interconnected neural networks (Mariani, 2016). Cognitive neuroscience, bridging the gap between biology, behaviour, and the mind, uses sophisticated methods to analyse these networks and their influence on cognition and behaviour. Researchers acknowledge the close relationship between mental representations and the underlying neural networks.

Research on neural networks aims to understand how brain structures support learning, behaviour, and knowledge acquisition (Olivieri, 2011). Several frameworks have emerged to explain these complex neural systems (see Pang et al. 2023) and shed light on intelligence and cognition.

These include the *4E Cognition guidelines, Connectomic theory, Network-Based Theory, and the Neuronal Recycling Hypothesis*.

While each has its own level of empirical support, they all share a focus on the importance of cortical connective systems, or networks of neurons.

The educational sciences are also grappling with how to integrate knowledge from neuroscience and psychology. The goal is to develop a distinct "neuroeducational epistemology" that leverages insights from other disciplines while maintaining its own foundational principles. This effort to define a unique role for educational science beyond pure neuroscience is explored in Chapter III.

The 4E Cognition Guidelines

Alongside brain research, a growing emphasis is being placed on the role of the body in shaping cognition. This perspective suggests that the mind isn't confined to the brain, but rather perceives and intuits through the complex bodily system, which can even extend beyond the physical body itself (Saphiro, 2019). Numerous theories have been proposed to explain how the mind can extend beyond the brain.

One such framework is the "4E Cognition" approach, which stands for Embodied, Enactive, Embedded, and Extended cognition. This approach argues that cognition and knowledge acquisition are not solely processes that occur within the head. Instead, they are embodied, meaning they are intricately linked to our physical bodies. They are also enactive, meaning our actions and interactions with the world shape our understanding. Additionally, cognition is embedded within a specific social and cultural context that influences our thinking. Finally, the 4E framework emphasises the extended nature of the mind, suggesting that cognition can be supported by tools and technologies external to the brain (Newen, De Bruin, & Gallagher, 2018).

This "4E" perspective is rooted in theoretical assumptions drawn primarily from the field of enactivism, which emphasises the active role of the body in shaping our understanding of the world.

The 4E Cognition Framework: *Embodied*, *Enactive*, *Embedded*, and *Extended Cognition.*

The 4E approach to cognition emphasises how our understanding of the world is shaped by more than just our brains. Let's break down each of the "E"s in this framework:

- *Embodied*: Our cognition is fundamentally tied to our physical bodies and sensory experiences. The way we perceive the world is influenced by our senses (sight, touch, taste, smell, and hearing) and how we interact with our environment. For example, the size and weight of an object feel different in our hands than they appear in a picture.
- *Embedded*: Our cognition is shaped by the social and cultural context in which we live. Our experiences, values, and beliefs are influenced by our families, communities, and the broader culture we are part of. This cultural and social context provides a framework for interpreting the world around us.
- *Enacted*: Our cognition is actively constructed through our experiences and how we interact with the world. As we solve problems, explore our environment, and engage in activities, we build our understanding. This "learning by doing" approach highlights how our actions contribute to our knowledge acquisition.
- *Extended*: Our cognition can be supported by tools and technologies that function as extensions of our minds. This includes everything from simple tools like pencils to complex technologies like computers. These external resources can expand our memory, processing power, and ability to access information.

Proponents of the 4E model argue that our bodies play a crucial role in shaping how we understand the world. Our bodies provide us with a meaningful representation of the world, not just through conscious reasoning, but also through a process of evolutionary selection and inherent biological capabilities. This suggests that some cognitive activities, like basic perception and response to opportunities for action (affordances), can occur without the need for symbolic thought.

This perspective is supported by neurocognitive experiments on perception, language, and thought. These experiments demonstrate how our cognition is inevitably shaped by the cultural environment we live in.

The development of the 4E paradigm is particularly interesting because it bridges the gap between two seemingly disparate areas: phenomenological tradition (Merleau-Ponty, 2002), this tradition emphasises the lived experience of the body and how it shapes perception; contemporary neuroscience: this field studies the physical mechanisms underlying cognition in the brain.

The goal of the 4E framework is to reconcile these two perspectives. It aims to connect specific brain states with the subjective experience of those states, considering both the biological processes and the personal meaning-making involved.

Early research suggests that it's possible to build a theory of meaning where a proposition's meaning is determined by a combination of factors: the agent's intentions and beliefs (internal factors) and external factors and influences from the environment (sometimes unknown factors).

For example, Gallagher (2008) argues that social cognition (embedded cognition in the 4E model) is directly influenced by how we imitate and mirror each other's behaviour (see Chapter II for a discussion on "brains in the classroom," Mariani, 2016). This suggests that our understanding of social situations might be processed directly by neurological mechanisms, or it could be shaped by external cultural cues (Carney, 2020).

The 4E model, despite its innovative approach, is not without controversy. While its theoretical foundation is valuable, some critics argue that the model needs stronger empirical support to be fully accepted in the scientific community. They caution against the risk of aligning the 4E model with perspectives from other disciplines (psychoanalysis, structuralism, cybernetics, philosophy) that may not fully align with neuroscientific principles (Carney, 2020).

It's important to acknowledge earlier work (e.g., bio-education by Fraunfelder, 1983) that highlighted the interconnectedness of body, mind, and knowledge. This challenged the historical dualism that separated learning (brain) from action (body).

For educational neuroscience, the concepts of embodied cognition and embodied learning emerging from the 4E model hold significant promise. These concepts provide a potential epistemological foundation for the field.

Specifically, there's value in revisiting ideas related to:

- Sensory didactics (explored in Section 4.4): this approach emphasises how learning can be enhanced by engaging the senses.
- Movement didactics: this focuses on how physical movement can contribute to learning.