WORKING
GROUP 02

CHAPTER

7

Contexts of educational neuroscience

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Educational neuroscience (EN) is a complex research field with a bidirectional relationship between neuroscience and education. The chapter examines the social, cultural, political, ideological and conceptual contexts of EN. One conceptual context for (educational) neuroscience is self-understanding of neuroscience, as a frame for research agendas and dissemination, including a model of explanation (reductionism versus holism) and a model of learning and the learner. When the aim of education is human flourishing, it is important to understand learners in their psychosocial, socio-economic and sociocultural contexts with the goal of holistic well-being. These contexts shape both the research field itself and its direct or indirect uses in/as educational practices. The chapter explores the challenges for EN, including those relating to complexity of learning and of translation to the classroom, research and inclusion, and its ethical implications.

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WORKING GROUP 02

CHAPTER 7

7.1 Introduction

The overall aim of this chapter is to examine the broad contexts of educational neuroscience (EN) in its relationships with formal educational institutions. Within EN, context is often viewed narrowly: for example, how the classroom environment, teaching and pedagogy impacts the individual student's brain structure and function as they learn in a classroom, or how socio-economic

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status (SES) or poverty impacts learning processes. In contrast, this chapter examines a broader meaning, namely, the social, cultural, political, ideological and conceptual contexts of EN as a research practice in its relation to education. Our aim in examining these broad contexts is not merely to describe them, but to critically examine them in the context of human flourishing **(WG1-ch1, ch2)**. In particular, discussions of flourishing bring to the foreground issues of inequality and oppression, which include the intersections of inequality along gender, racial, socio-economic, religious, and cultural dimensions **(WG2-ch4)**.

Our focus on the broad context of EN leads us to address a cluster of contextual issues. The broad contexts include exploring grounding concepts that shape EN as a field, including models of explanation and concepts around learning and the learner. We also examine societal contexts for EN, including political/economic factors, as well as social and cultural dimensions. We also have included what we call 'challenges' – including those around the complexity of learning and how research findings from the lab translate to classroom practices. Other sorts of challenges centre around research and validity, as well as inclusion and ethics. These challenges situate what sorts of EN research are often encouraged and funded by policy-makers as well as how. Our underlying question is: how do these contexts shape EN's support of an educational vision of flourishing?

7.2 Educational neuroscience

EN is a complex research field with a bidirectional relationship between neuroscience and education. Although we use the term 'educational neuroscience', we recognize other ways of naming this field, including mind, brain and education (MBE) and neuroeducation **(Knox, 2016)**. Published papers in EN, a rapidly growing research field, have increased exponentially over recent decades **(Feiler and Stabio, 2018)**. Broadly speaking, EN often has a systems-level understanding of learning, adopting an integrated view that 'contextualises learning across multiple dimensions, encompassing well-being, social cognition, affective processing, nutritional factors, genetic factors, sleep, and exercise'

EN researches the brain to understand mechanisms of learning – including research into the interplay between the brain and the learning environment – to improve learning outcomes and experiences by informing teaching and learning practices **(Antonenko, 2019; Thomas and Ansari, 2020)**. EN often has a systems-level understanding of learning, adopting an integrated view that 'contextualises learning across multiple dimensions, encompassing well-being, social cognition, affective processing, nutritional factors, genetic factors, sleep, and exercise' **(Seghier, Fahim and Habak, 2019, pp. 2–3)**. Understanding learning mechanisms serves multiple educational purposes, including improving teaching **(Schwartz et al., 2019; see also WG2-ch10)**, understanding teachers' beliefs and expectations **(Hook and Farah, 2013)**, making learning more enjoyable and promoting more positive interactions among students **(Howard-Jones, 2014)**. EN addresses questions such as how the body's physiology influences the learning brain **(see WG3-ch2)**; how the brain learns to read and write and acquire literacy **(WG3-ch5)**; how broader learning environments influence the learning brain **(WG3-ch2, ch7)**; and how studying individual differences can inform and update curricula and pedagogical choices **(WG2-ch8; WG3-ch5)**, assessment **(WG2-ch9; WG3-ch5)** and teaching practices **(WG2-ch10; WG3-ch5, ch6)**.

As a research field, EN has been described as a 'syntheses of theories, methods, and techniques of neurosciences, as applied to and informed by educational research and practice' **(Patten and Campbell, 2011, p. 1)**. With an emphasis on cognitive and developmental neuroscience, EN is comprised of two distinct clusters of disciplines: neurosciences (neurochemistry, molecular biology, electrophysiology, neuroanatomy, neurophysiology, networks) and educational studies (pedagogical studies, learning theories, educational psychology, cognitive psychology, educational sociology, organizational studies). The intersections create internal tensions within EN: the

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neurosciences tend to embrace a narrower 'neuromolecular style of thought' **(Rose and Abi-Rached, 2013, p. 41)**, while educational studies tend to embrace broader, more normative styles of thought **(Biesta, 2010)**. As things stand, 'synthesis' remains elusive in the EN field, which continues to manifest significant tensions and disagreements over fundamental concepts, approaches and evidence **(Flobakk, 2015)**. Dynamics around answers to basic questions, and views of integration, are continuing complexities for EN and its relationship to education. Whereas the neuroscience cluster is often couched in terms of empirical science of data, observation and theory, the educational cluster is more typically given in normative language, such as appropriateness, desirability and ethical visions **(Biesta, 2010, pp. 47–48)**. This means that education's markers are often couched in more holistic behavioural metrics, whereas neuroscience's markers are more typically given in empirically generated measurements.

An interesting and important recent example of EN research centres around SES as a significant factor in learning **(Farah, 2017; Ozernov-Palchik et al., 2019; Rexrode et al., 2019; Fracchiaet al., 2020)**. SES is a broad-spectrum designation that provides a 'pervasive context throughout one's life', affecting not only physical health and well-being but also cognition and agency **(Kwon, Hampton and Varnum, 2017, p. 383)**. One particular dimension is the way that poverty-related stress affects brain development and processing **(Kim et al., 2013; Geronimus et al., 2015; Tomar et al., 2015)**. Some researchers, taking an integrative approach **(Lende, 2012)**, look to sources of stress in social factors such as policy-produced economic inequality, and seek to understand how children respond **(Ellwood-Lowe, Whitfield-Gabrieli and Bunge, 2020)**. This research challenges explanations that reinscribe a collective pathology onto those in poverty **(Wax, 2017; Pitts-Taylor, 2019)** while ignoring the strengths of those in poverty **(Frankenhuis and Nettle, 2020)**. This is a good example of how EN supports education's interest in human flourishing.

7.3

Current contexts

The context of human flourishing gives direction to certain questions about EN. We might ask how EN has reshaped our understanding of learning – then human flourishing gives direction to whether, for example, broadening or narrowing education's conceptions of learning is beneficial for student well-being. We might ask how EN impacts policy-makers and other (non-educator) stakeholders' view of education and learning – then, normatively, human flourishing frames adjudications of the impact of those policies on education. Human flourishing even provides context for understanding and evaluating more helpful and less helpful metaphors for scientific explanations and models of the relationship between educational practice and neuroscientific research: conceptual tensions over the relationship is – or should be – application of theory to classroom practice, or whether it is – or should be – more embedded models. It helps stakeholders decide whether goals of human flourishing in education are better served through filtering EN through psychological and sociological theories of learners

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as persons (in relation, in social settings), or whether it is better to model learners as brains (learning in isolation, in the head). The lens of human flourishing even provides the context for deciding whether the impact of EN is more beneficial or harmful, giving direction to how EN ought to impact educational practice.

7.3.1

EDUCATIONAL NEUROSCIENCE'S MODEL OF EXPLANATION: REDUCTIONISM AND HOLISM

One cluster of EN contexts is conceptual, and centres around understandings of EN as a field of research. Although not typically thought of as contextual, understandings of EN as a field of study tacitly frame the field of EN. These provide often unstated contexts for what is envisioned as possibilities and limitations of the various methods and models (approaches, styles, self-understandings) that are brought to the research and dissemination, including implications for educational practices. Should EN be seen as a basic science (with controlled conditions, lab settings) that subsequently is applied to school? Or should it be an 'embedded' model, where researchers – when doing their research – are directly embedded in schools, in situ. Further, is it at base a molecular/cellular science, a cognitive psychological science or an emergent/enactive science? Is its primary mode of explanation reductionist or emergentist/holist?

One conceptual context for (educational) neuroscience is the model of self-understanding of neuroscience, as a science, that frames its research agendas and dissemination. This includes centrally what counts as evidence and what constitutes an explanation. One enduring temptation for EN is to draw

Reductionist accounts typically assume an analysis is required which involves the breaking of complex phenomena into their simplest components, and then explaining each component with a particular underlying mechanism.

its scientific self-understanding from neuroscience as a field of research. In turn, neuroscience's enduring explanatory approach often embraces what is called reductionism **(van Riel, 2014)**. This approach is centred in 'explanatory reductionism' **(Borsboom, Cramer and Kalis, 2019)**, the idea that learning behaviours can be explained in biological (neuromolecular, neourological) terms. A reductionist explanation typically uses metaphors of levels and mechanisms: biological organization at a higher level is explained by mechanisms at a lower level **(Kaplan, 2015; Eronen, 2021)**. Behaviour at the higher level (e.g. person) is explained by a cause-and-effect mechanism at the lower level (e.g. brain) **(Illariand Williamson, 2012; Soom, 2012)**. An example from high school biology is explaining classical (mendelian) genetics of (say) eye colour in terms of molecular genetics **(Brigandtand Love, 2017)**. Reductionist accounts typically assume an analysis is required which involves the breaking of complex phenomena into their simplest components, and then explaining each component with a particular underlying mechanism. In neuroscience's reductionist paradigm, cognitive phenomena at a higher level (the learner as person) are analysed into basic components and then explained by neurological mechanisms at the lower level; the higher-level phenomenon is said to be explained, without remainder, by something at the lower level (the brain) **(Bickle, 2003)**. Cognitive phenomena such as attention, memory, thought, perception and judgement typically are explained by localized neurological mechanisms **(Kaplan, 2015)**.

The reduction metaphor highlights several conceptual issues. The phenomenon to be explained is often not reducible as given but needs recasting or redescribing in terms that are more amenable to analysis. Often this means simplifying its complexity by identifying and isolating central parts of the behaviour to make them explicable by underlying (localized) mechanisms. For example, analysis of a complex psychological phenomenon such as learning requires simplifying it into 'functional sub-types' that are 'co-extensive with neuropsychological types' **(Soom, Sachse and Esfeld, 2010, p. 7)**. This makes the psychological sub-type of learning, say, how to do mathematics or how to read, amenable for mapping onto localized neural correlates **(Dehaene et al., 2010; Hruby and Goswami, 2011)**. In turn, a reductionist mode of explanation depends on the assumption that there can be no change in mental activity without a correlative change in brain activity. To make this explanatory metaphor plausible, complex learning activities (such as reading) are recast as functional subtypes, namely, in terms of their (potential) causal relationships. This allows a particular observable behaviour (e.g. reading) at the higher level to be explained in terms of causal mechanisms at the lower level **(Borsboom, Cramer and Kalis, 2019)**. But, despite the ubiquity of this approach in neuroscience, critics point out that 'causation cannot just be literally read off experimental findings' **(Andersen et al., 2018, p. 238)**. And, perhaps equally troublesome, the notion of causation used in these explanations is often questionable, conflating causation with correlation **(Marchionni and Reijula, 2019)**.

This leads to a narrow view of the content of mental state, typically interpreted in representational terms: the mind contains mental representations of the world, and thinking involves producing, recalling and recombining mental representations **(Joldersma, 2016a)**. The reduction then can occur by explaining the mind's manipulations of mental representations through the brain's computations of information, often imagined as being carried in physical symbols. This neural correlation is often interpreted in causal terms: particular contents of cognitive states are caused by particular neural states. This typically rides on the assumption that brains 'are for' information (and symbol) manipulation and that neural processes are forms of symbol manipulations **(Glenberg et al., 2007)**. These assumptions are the conceptual context for EN explanations using metaphors of information, computation and representation **(Borck, 2011)**.

This narrow view of content typically assumes learning is context-free: all that is important to learning (thinking, cognizing) is inside the head, and thus in the brain. The social and physical worlds, including the lived body, are then reduced to mere external inputs that can be bracketed in modelling how learning happens **(Ashourvan et al., 2019)**. Further, the idea of information associated with the narrow view of mental content is ambiguous. In cognitive science (psychology), the term 'information' is typically used to include meaning, namely, semantic content about the world. In neuroscience, often the idea of information, called 'Shannon information', refers to correlations (statistical differences) between two brain states, while remaining agnostic concerning (mental) semantic meaning **(Maley and Piccinini, 2015, p. 80)**. The contrast between the two notions of information is important: 'Shannon information' is purely quantitative, whereas (cognitive) semantic content is qualitative, and resistant to quantification. This fundamental difference undermines the narrow interpretation of cognition required for the one-to-one mappings of neural correlations used in reductionist explanations that are standard in much of neuroscience.

This explanatory mode is the context for claims that are typical in EN about learning: brains learn, brains think, brains imagine. Some educators and educational researchers, however, argue that these neuroscientific statements about brains revolve around a category mistake, or what philosophers call a 'mereological fallacy': that the brain 'is made to stand for the whole in some reified sense' **(Williams and Standish, 2016, pp. 19, 20, emphasis in original)**. For example – this criticism states – pain is not a brain state; pain is a conscious feeling, often localized somewhere in the body. This critique says that when EN talks about brains learning, they are using the wrong category; just

... brains are coordinators of dynamic patterns of embodied (sensori-motor) interactions with one's surroundings.

like it is a category mistake to say that legs walk, it is a mistake to say that brains learn when we mean that a whole person does so. Learning is not a neuronal activity but a human one **(Arievitch, 2017; Bannell, 2019)**. Reductionism is an enduring if implicit continuing context for EN in its relationship to education.

However, this model is changing. Recently, other modes of explanation have entered the picture, ones based in the metaphor of emergence and emphasizing holism, taking into account the brain's context **(Moreno and Schulkin, 2019)**. Rather than using the metaphor of the brain as a computational processor (a complex machine/ mechanism) isolated inside the skull, the metaphors of these explanations cluster around the idea that brains are coordinators of dynamic patterns of embodied (sensori-motor) interactions with one's surroundings. This metaphor draws on a model of open dynamic systems, connoting interacting elements out of which emerges a stable but dynamic whole. The metaphors of 'open' and 'dynamic' assume non-static, non-linear (non-mechanical) interactions by the system's elements; the metaphor of 'system' intimates an emergent whole that isn't merely the sum of the particular processes that support and sustain it: the whole isn't directly proportional to the sum of its dynamic elements. In this explanatory model, the brain is taken to be a dynamic, complex system **(Van Gelder, 1998; Schöner, 2008; Engel, 2011)**; macro-scale patterns emerge out of micro-scale feedback loops (recurrent networks) and distributed processing (non-linearity), an emergent self-organization that constrains (shapes) the processes that support it. When the brain is modelled as a dynamic open system, its supporting dynamic elements are said to be constrained – coopted – by higher-order (global) dynamic patterns of brain action. Although there may still be talk of levels, this is more a heuristic device than referencing reducible hierarchical levels, and is instead bound up with integrative explanations of complex systems.

Rather than viewing learning in a reductionist and narrowing way, learning is modelled as a process undertaken by an embodied student, embedded in their surroundings.

This approach of thinking about the brain has changed the notion of cognition as well. Some use the metaphor of enactment, theorizing an enactivist understanding of cognition: they imagine a substantive, enduring relation between mind, brain, body and surroundings embodied. According to this model, brains are not for thinking (traditionally understood as computation or symbol manipulation); rather, brains are understood as a central part of an embodied nervous system that function as a guide to bodily action, activating and coordinating the body's movements in its surrounding and experienced world – a sensorimotor coupling of body with world. Further, in this emergent model, the body is not (first of all) an object (open to scientific discovery) but a subject: an intentional being trying to exercise (bodily) understanding of the experienced world by moving about in it **(Thompson, 2005; de Gelder et al., 2010; Joldersma, 2016a)**. Explanations of this model are modelled as emergent, non-linear and non-deterministic. This approach attempts to retain, in its research and conceptualizations, that 'a child surrounds this brain' **(Rapp, 2011, p. 3)**. Rather than viewing learning in a reductionist and narrowing way, learning is modelled as a process undertaken by an embodied student, embedded in their surroundings, with anticipations of particular ways of living; active participants in families and communities. Instead of bracketing these factors, an emergent, dynamic model of the brain can more readily include these in its modelling of learning.

An important development in this regard is the ambitious 'connectome' approach to brain mapping **(Sporns, 2011)**. The term 'connectome', echoing other 'comprehensive understanding' undertakings such as the genome project, endeavours to create a comprehensive mapping of all the interconnections in the brain. More than just advances in technique and data sharing, this approach is a new paradigm **(Elam et al., 2021, p. 2)**, understanding the brain as a complex network or, more accurately, clusters of

... understanding the brain as a complex network or, more accurately, clusters of interconnected structural and (functional) dynamic networks in the context of the whole person interacting with their environment.

interconnected structural and (functional) dynamic networks in the context of the whole person interacting with their environment. The connectome approach of mapping neural networks has given us new insights into the brain in its whole-person context, including, for example, around individual differences of autobiographical memory **(Petrican et al., 2020)**, propensities to trust **(Feng et al., 2021)** and educational attainment **(Bathelt et al., 2019)**. This non-reductionist approach is promising in the EN context.

7.3 .2

EDUCATIONAL NEUROSCIENCE'S MODELS OF LEARNING AND THE LEARNER

Another important conceptual context for EN is its understanding of the learner (student) and learning. What models and metaphors of the student (the learner, the pupil, the child) typically shape EN? What relationship is often assumed between mind and brain, between person and neuron, between body and head? Does EN have a Western bias, mostly generalizing from Western populations in industrialized and wealthier nations? Do the participant pools studied in EN research encompass social and cultural diversity? Assumptions about 'the learner' continue to tacitly frame EN and its relationship to education.

The continuing allure of EN research is its promise to help with the effectiveness and efficacy of educational practices – fixes for a perceived broken system **(Flobakk, 2015)**. Promising results include: MRIs showing that intensive remedial educational interventions in reading instruction change the brain's white matter in poor readers **(Simos et al., 2002)**; fMRIs and fNIRSs successfully exploring brain regions supporting language learning, mathematical processes and executive functioning **(Artemenko et al., 2018)**; EEGs helping illuminate a variety of complex cognitive tasks, including

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cognitive load, knowledge representation and when cognition occurs **(Örün and Akbulut, 2019)**; eye-tracking aiding in understanding visual and other forms of attention **(De Smedt, 2018; Antonenko, 2019)**. Recent research suggests that these sorts of studies are promising in a number of educational areas: in developing causal models of non-typical cognitive development (attention deficit hyperactivity disorder (ADHD), autism, dyslexia, dyscalculia, cognitive impairment); in predicting or prognosing educational outcomes, especially early identification of students who might struggle later on in schooling; and in understanding educational learning at a biological (brain, neurological) level **(De Smedt, 2018)**. Of course, to translate 'promise' into knowledge that is useful in the classroom requires researchers to partner with educators in the design, implementation and interpretation of such research.

EN often offers cognitively understood learning theories **(Antonenko, 2019; Lin, Parsons and Cockerham, 2019)**. However, from the perspective of whole-person flourishing, these theories have a narrow understanding of learning: they are individualist and cognitive, often minimizing or externalizing important dimensions of the learner such as emotional depth **(Immordino-Yang, 2015)**, sociocultural contexts **(Han, 2017)** and normative visions **(Biesta, 2019)**. Moreover, traditional cognitive learning theories are prone to further simplification: learning is analysed into a complex (hierarchical) tree of components amenable to isolation for neuroscientific investigation: processing speed, mental rotation, diagrammatic reasoning, short-term memory, working memory, long-term memory, visual attention **(Antonenko, 2019)**. Learning at the cognitive level is then expressed as the formation of associations while learning at the neuroscientific level is often described as a permanent change in neuron firing and wiring **(Gallistel and Matzel, 2013)**. These narrow interpretations of learning are often in tension with the broader senses of learning that educators ascribe to learners.

... those embracing a neurodiversity conceptualization ... –question the pathologizing of neurological differences as impairments and deficits.

A related conceptual context that can influence how EN models the learner and learning centres around a bifurcation of normalcy/pathology. Although the terms 'normal' and 'abnormal' have helpfully been replaced with terms like 'typical' and 'atypical', in the popular imaginary of many societies the terms 'normal' and 'abnormal' continue to buttress education **(see WG3-ch3 and WG3-ch6 on discussion related to this topic)**. This category bifurcation is often expressed in medical terms, continuing the 'medicalization of deviance' **(Conrad, 2013; see also Cohen, 1983; Petrina, 2006)**. Medicalization involves categorizing differences as deficits or disorders, describing them as pathological, using medical concepts and perhaps requiring medical intervention **(Kaczmarek, 2019)**. For example, differences in discipline-specific skills – including reading (phonemic awareness), mathematics (numeracy, symbol understanding) and science (concept recognition) – are prone to homogenization into the bifurcated categories of typical (normal) and deviant (pathological), as are generalized abilities such as executive functioning and emotional regulation **(Thomas, Mareschal and Dumontheil, 2020)**. Or, learning disability is traditionally defined as a neurobiological disorder, marked by deficits in reading, writing and/or mathematical abilities **(Mırıcı et al., 2018)**. EN, then, often researches contrasting neural correlates within the bifurcated groups **(Di Liberto et al., 2018; Mayes et al., 2018)**, supporting the normalcy/pathology schema.

However, others in EN – for example, those embracing a neurodiversity conceptualization – question the pathologizing of neurological differences as impairments and deficits **(Kapp, 2020)**. The deficit model is being challenged in various ways, not only through conceptualizing neurological differences as neurodiversity **(Lambert, 2018)**, but also from a 'strengths' approach **(West, 2020)**, from a 'dimensions' perspective on learning differences **(Child et al., 2019; Bernabini et al., 2021)** and by challenging the category

schemas themselves **(Protopapas and Parrila, 2018)**. Further, recent EN recognizes that '[n]ormal and abnormal cannot be defined without understanding the beliefs, values, and power structures of a cultural group' **(Mason, 2015, p. 345)**. Certainly, many helpful assessments have resulted from medically conceptualized diagnoses, where struggling students have been significantly helped **(Ansari, 2015a)**. Nevertheless, the contextual question that EN needs continually to ask is: When is it helpful and when is it not helpful for EN to rely on a bifurcating medical model with respect to students' flourishing? Given the wide variations in learning abilities – and astonishing variability between persons – the normalcy/pathology schema needs constant scrutiny **(Matus, 2019)**, particularly in the context of the broader understanding of human flourishing rather than human capital development.

When the goal of education is human flourishing, the broader senses of learning remain important; understanding learners in their psychosocial, socio-economic and sociocultural contexts is vital for approaches that accent the broader goal of holistic well-being. EN would do well to continue to expand its self-understanding of what constitutes learning, and who is the learner. There has been some promising research in that regard: including the importance of emotions in learning **(Immordino-Yang, 2015)**; situating EN in a sociocultural context **(Hall, Curtin and Rutherford, 2013)**; recognizing that learning is undertaken by embodied learners **(Fugate, Macrine and Cipriano, 2019; Shapiro and Stolz, 2019)**; acknowledging that learners are enactively embedded in their surroundings **(Gallagher and Allen, 2018)**; and modelling the brain as a dynamic open system **(Ashourvan et al., 2019)**. The latter has been used, for example, to think differently about music learning **(Schiavio et al., 2017)**, moral development **(Sankey and Kim, 2016)** and science study **(Lamb, Cavagnetto and Akmal, 2014)**. These more holistic, emergent, contextual and dynamic approaches to understanding the learner – and modelling learning – has promise for neuroscience research supporting human flourishing.

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7.3.3

CONTEXTUAL SOCIETAL FACTORS: POLITICO-ECONOMIC, SOCIOCULTURAL

EN as a field is profoundly affected by its social, cultural, political, and economic contexts. Understanding EN's contexts therefore requires making visible multiple societal contexts that shape both the research field itself and its direct or indirect uses in/as educational practices. These include what could broadly be called politico-economic and sociocultural contexts. By 'political' we mean systems of power, often in the form

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of legislated policies, funding directives and standards; by 'economic' we mean systems of capital exchange, often in the form of entrepreneurship, commercialization and capitalization. By social we mean a realm of society integrated by a sense of community (solidarity), rather than power (the political realm) or money (the economic realm) – a sphere that social theorist Jurgen Habermas **(1991)** calls 'civil society'; by 'cultural' we mean systems of collective expression that show variations around the globe in various societies. Although conceptually distinguishable, these contextual factors operate in the same societal spaces and mutually influence each other.

7.3 .3 .1

POLITICO-ECONOMIC CONTEXTS

EN – as well as other educational research – shows that brain functioning, human development and student learning are all complex processes. However, within what can broadly be called the 'political context', this complexity is often bracketed or minimized: politicians, policy-makers, educators, parents and business entrepreneurs often want simple solutions and strategies. The continuing pressure to simplify is not neutral but has profound effects on how students might or might not flourish. As EN is often seen as a 'remedy' for a failing education system in the public imaginary **(Flobakk, 2015)**, it comes as no surprise that EN findings have been of great interest to educational policy-makers **(Thomas, 2017)**. For example, oversimplifications of EN's findings become tempting bases for commercial products. Particularly when formal schooling, as a social institution, is under relentless pressure to improve with respect to a globalizing regime of standardized testing, commercial products become tempting supplements which might not only complement pedagogical practices, but – more problematically – supplant them.

The general public, including professional educators and policy-makers, often don't have the background to assess the validity of the claims made about commercial products.

Ever since the 'decade of the brain', business entrepreneurs have leveraged neuroscientific knowledge into commercial products, typically offered as aids to learning. Some, such as LearingRx, CogMed and Lumosity, target students to use computer-centred activities; these products claim to train the brain to become more efficient and effective in learning. Others make claims based in brain plasticity research; they claim their product enhances particular neurological pathways, boosting cognitive functions like memory and attention **(Hurley, 2012)**. Others, including Brain Targeted Teaching, Fast ForWord® and MindUP **(Busso and Pollack, 2015)**, target teachers and other educators, assuring them that their product will enhance their effectiveness in teaching. The general public, including professional educators and policy-makers, often don't have the background to assess the validity of the claims made about commercial products. These products typically don't distinguish between – and sometimes even conflate – products that are actually supported by neuroscientific research, those that are loosely derived from such research, or products that are merely inspired by brain research **(Sylvan and Christodoulou, 2010)**. Such vagueness can lead to misrepresenting such commercial products in their effectiveness. Continued critical appraisals of commercial products is vital; the accuracy of commercialized claims requires continued, informed assessments.

Thankfully, research critical of commercialized products is on-going; there are many who bring a critical eye to commercial and clinical products **(Redick et al., 2013; Zickefoose et al., 2013; Walker, Thompson and Oliver, 2014; Shute, Ventura and Ke, 2015; Raz and Rabipour, 2019; Naufel and Klein, 2020)**. Some of these focus on the accuracy of the claims, while others address more explicit ethical dimensions including issues of accountability **(Martinez-Martin and Kreitmair, 2018)**. However, concerns about faulty products can have alternative motivations: their potential to

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dampen 'economic growth' **(OECD, 2019, p. 5)** or their possible harmful effects on 'human flourishing' **(Kreitmair, 2019)**. Harm can take various forms: actual harm to brain development, but also stigma around mental health or self-perception. Because financially motivated commercialization can harm students, especially the most vulnerable populations, it remains crucial for educators, researchers and policy-makers to make informed decisions about commercial products based not only on credible research but also on what ethical vision of living together is being promoted.

The issue of commercialization of EN research brings to light a broader politico-economic context: neoliberalism. Choudhury and her co-workers note that 'scientists are working at a time of unprecedented politicization through commercialization of research' **(Choudhury, Nagel and Slaby, 2009, p. 68)**. Indeed, the discourse analysis research by Flobakk **(2015)** shows a clear link between EN and neoliberalism within the political field and how findings from EN are used to justify political decisions. Neoliberalism is a cluster of ideas that relate individuals (citizens, consumers) to power (governments) and money (economies) **(Harvey, 2005, 2016)**. At its simplest, neoliberalism is a vision of small government that commodifies more and more areas of society to bring them into the market economy for profit and capital accumulation. For the last number of decades, formal education has become a rich terrain for commodification, commercialization and capital accumulation. For example, outsourcing assessment to formally non-profit organizations like the College Board 'netted them an estimated make $150–$160 million in profits for 2019' **(Financial Samurai, 2020)**. The College Board (in turn) outsourced its test scoring to the for-profit Pearson Educational Measurement, the USA's 'largest commercial processor of K-12 student assessment tests', where educational assessment has been narrowed to fit Pearson's 'online proprietary Electronic

Performance Evaluation Network (ePEN)' **(Pearson, 2003)**. Such standardizing and outsourcing means that what counts as learning gets narrowed, to fit with what is measurable by this proprietary mechanism. This narrowing is not neutral; there is evidence that it affects populations of students differentially, showing greater harm to those on the margins of society **(Au, 2015)**. These neoliberal moves within formal education form an economic context within which EN operates; the narrowing of what constitutes learning through such standardization impacts EN's terrain of research.

This narrowing through commercialization of assessment instruments goes hand in hand with a more general neoliberal narrowing of student learning – for human capital development **(DeLissovoy and Cedillo, 2016; OECD, 2019)**. Global policy drivers, such as the OECD, shape what counts as cognition and knowledge in education **(Maire, 2020)**. Such narrowing of education emphasizes basic skills and practical knowledge so that students can become more effective workers permanently ready for the changing, precarious economy **(Olssen, 2008; Brown, 2011)**. Neuroscience can and at times has been coopted by this neoliberal vision **(Rose and Abi-Rached, 2013; Pitts-Taylor, 2016)**: supporting the narrowing of learning as human capital development **(Millei and Joronen, 2016)**; legitimating 'grit' and 'resiliency' research **(Wang et al., 2017)**; and coopting of plasticity research to 'responsibilize' the learner **(Pitts-Taylor, 2010; Joldersma, 2016b)**. This, however, is not intrinsic to EN: it equally supports educational practices that lead to flourishing for all students, rather than reinforce savage inequalities.

In contrast to neuroscience research which looks exclusively at internal processes … social neuroscience focuses more broadly on the brain's function in its social context.

7.3 .3 .2

SOCIOCULTURAL CONTEXTS

Although traditionally EN has focused narrowly on the mind and brain in isolation from humans as embodied persons living in social settings, emphasis on embodiment of mind and brain, and on the

embeddedness of (embodied) persons in society and culture, has entered the field. This has, in turn, raised new awareness of social and cultural contexts for EN.

The recognition that humans are social beings has given rise to a new field: social neuroscience **(Todorov, 2011; Decety and Cacioppo, 2015)**. In contrast to neuroscience research which looks exclusively at internal processes such as attention, memory, representation, executive functioning and reasoning, social neuroscience focuses more broadly on the brain's function in its social context. As a field, it investigates how the brain supports 'communication, social perception and recognition, impression formation, imitation, empathy, competition, cooperation, pair-bonding, mother-infant attachment, bi-parental caregiving, social learning, status hierarchies, norms and cultures, social learning [sic], conformity, contagion, social networks, societies, and culture'

Social neuroscience makes explicit the already implicit social context for all brain functioning, and thus for all neuroscientific investigation.

(Cacioppo and Cacioppo, 2020, pp. 7–8). This long list of topics is not in direct competition with those of more traditional EN; however, neither is it simply a neat division of labour. Social neuroscience's operationalization of the recognition that humans are social creatures means that the topics of EN ought to take the person's social situatedness into account, even when investigating seemingly more internalized processes such as attention, memory, reasoning and the like. For example, the importance of human interactions such as social touch, both in early development **(Gliga, Farroni and Cascio, 2018)** and in later life **(Reddan et al., 2020)**, point to important continuing social contexts for both brain development and human flourishing. Social neuroscience makes explicit the already implicit social context for all brain functioning, and thus for all neuroscientific investigation.

Social neuroscience is becoming embedded in EN. When learning itself is not considered as something that occurs in the individual brain, in isolation, but is itself a social process, then EN is no longer restricted to asking how the brain supports learning, but how learning itself changes (reorganizes) the brain **(Richaud, Filippetti and Mesurado, 2019)**. This lens looks at context by, in a sense, flipping the script: the brain is shaped by learning experiences, as it is by other social interactions. Social neuroscience in education attends to the social roles of communication and collaboration in learning: for example, social processing of other people's beliefs and feelings or attending to the developing brain in its socially embedded context **(Immordino-Yang, Darling-Hammond and Krone, 2019)**. In this regard, hyperscanning research in neuroscience is a promising development in social neuroscience **(Misaki et al., 2021; Czeszumski et al., 2020)**.

Further, as Western cultures move beyond their eurocentrism, the visibility of cultural diversity and influence within and between societies has become increasingly evident. Culture is typically understood as ideas, beliefs, values, The field of cultural neuroscience takes into account how cultural variation across the globe might influence not only how people think and act, but also how this influences brain functioning.

norms and practices shared by groups of people. The emerging field of cultural neuroscience is changing our understanding of the brain. As a field, it draws from anthropology, cultural psychology, neuroscience and population genetics; its research focuses on interactions between culture and biology, including how neural processes are affected by cultural traits and relations **(Chiao, 2010; Han, 2017; Sasaki and Kim, 2017; Pedraza, 2020)**. The field of cultural neuroscience takes into account how cultural variation across the globe might influence not only how people think and act, but also how this influences brain functioning.

The importance of the context of culture for EN is becoming clearer. When 90 per cent of neuroimaging studies come from Western industrialized countries, with 12 per cent of the world's population **(Chiao, 2010, p. 5)**, generalizing the results across cultures is problematic. Cultural neuroscience has found distinct cultural influences on brain function for a variety of important social interactions: valuing individualism or collectivism; preferring social dominance or egalitarian norms; identifying with one's cultural group (racial or ethnic identification); seeking social support; visual cognizing, perceiving and attention; developing language and meaning; understanding fairness; and regulating emotions **(Chiao, 2010; Han, 2017; Pedraza, 2020)**. The broad array of cultural influence on neural processes means that, on the one hand, interpreting many current educational neuroscientific studies requires caution about overgeneralizing, while on the other hand, EN needs to attend more systematically to the context of cultural variability. Moreover, when culture itself is connected to power, bias and oppression, the context of neuroscience expands further, to include contextual issues of racism and injustice **(Malinowska, 2016; Lewis, 2020)**. EN – particularly in its inevitable connection with the culturally indexed practice of education – does well to consider the cultural differences in its research and applications.

7.4 Challenges to educational neuroscience

The continuing contexts of EN include a set of challenges that arise in its relation to educational practices and activities such as teaching and learning. Education as a field of research gives access to reality in a certain way, while neuroscience as a field of study gives access to reality in a markedly different way.

7.4.1 CHALLENGES RELATED TO COMPLEXITY OF LEARNING

As we have seen previously, not only is the brain a complex

... the learning crisis is related to the fact that many education systems across the developing world have little understanding of who is learning and who is not.

system, but formal education is a broad and complex concept as well. A recent report by the World Bank **(2018)** argues that the world is in the midst of a learning crisis: education should not be seen as merely schooling but should focus more on learning. Learning in school is not simply the acquisition of knowledge and skills but also includes the acquisition of values, beliefs and habits. In addition, learning always happens within the political and social context of a particular school and school context. As such, learning in educational institutions is a complex intersubjective pattern of action involving motivations, relationships with teachers and peers, familial settings, as well as societal policies for education. Finally, the learning crisis is related to the fact that many education systems across the developing world have little understanding of who is learning and who is not.

EN has already shown that it can go beyond what psychology can offer education; it can show not only possible cognitive mechanisms to explain who will benefit from interventions or not but, more importantly, it can show which one is actually delivered by the brain **(Thomas, Ansari and Knowland, 2019)**. As such, EN does not just provide insight into who is learning and who is not, it can also provide better insight into what learning is and, therefore, how learning can be measured more accurately.

However, the child's educational outcomes, as shown in Urie Bronfenbrenner's writings **(e.g. Bronfenbrenner, 1979)**, are also impacted by wider school, societal and familial as well as governmental factors. EN can improve educational outcomes by showing how the most proximal factors such as ability, motivation and attention, health and nutrition can impact learning **(Thomas, Ansari and Knowland, 2019)**. However, the impact of EN on other aspects of learning such as the institutional, professional, wider political, societal and economic influences on learning is still limited.

... recent research in EN has started to explore factors that are important to the wider social classroom environment, such as the mechanisms underpinning social and emotional processes that may impact on classroom behaviours.

Yet, recent research in EN has started to explore factors that are important to the wider social classroom environment, such as the mechanisms underpinning social and emotional processes that may impact on classroom behaviours. This includes mechanisms that underpin gaze processing, joint attention, face processing, action observation, reasoning about other people's mental states, emotion regulation as well as peer acceptance and rejection **(Blakemore et al., 2013; Hoorn et al., 2016; Martin and Ochsner, 2016)**. Although improved social and emotional well-being – for example, yoga training **(Butzer et al., 2016)**, mindfulness training **(Felver et al., 2016; Wheeler, Arnkoff and Glass, 2017)** or the impact of pollution on learning **(Annavarapu and Kathi, 2016)** – can facilitate learning and improve educational outcomes, neuroscience findings on social and emotional processes have not yet been systematically applied to classroom interventions.

7.4.2

CHALLENGES RELATED TO RESEARCH

Whenever research areas overlap, challenges arise around appropriate methods and what constitutes data, on the one hand, and interpretations of basic educational concepts, such as learning, on the other **(Howard-Jones, 2008, 2011)**, and this does not yet recognize the conceptual challenges within educational research itself. For example, there is no firm agreement on what counts as 'legitimate' knowledge or 'good' teaching, where the term 'good' signals something normative rather than effective **(Biesta, 2009, 2017)**, which is often situated in different visions of the role of education in society and what counts as a good society. These challenges around self-understandings form tacit but important contexts for EN in its relation to education, including its support for education's goal of human flourishing.

EN as a cluster is better served with a self-understanding of 'openness, flexibility, and disciplinary pluralism' that is 'problem-centered, integrative, and innovative'.

Attempts in EN at integrating the various clusters of research – the 'biological, behavioral, and social contexts' **(Knox, 2016, p. 6)** – is the difficult task of bringing together different discourses, meanings and depictions of reality. Rather than be concerned with boundaries of academic disciplines or building bridges between research areas **(Bruer, 1997, 2008)**, EN as a cluster is better served with a self-understanding of 'openness, flexibility, and disciplinary pluralism' that is 'problem-centered, integrative, and innovative' **(Knox, 2016, p. 6)**. However, even a transdisciplinary perspective – being open, flexible and problem-centered – does not necessarily address the foundational beliefs that shape the methodologies and theories of the various disciplines being transcended **(Palghat, Horvath and Lodge, 2017)**. Certainly the potential role of co-designing research projects and collaboration across disciplines is important and a significant step towards transcending the limitations of any one discipline. But because basic beliefs about reality, explanation and application will continue to shape the integrations and innovations of EN, continuing contextual questions need to include: Who gets to adjudicate the translations of the knowledge from various disciplines into solutions for transdisciplinary problems? Whose view of access to reality is privileged? For example, some might believe in 'positive realism', others might hold a 'constructivist viewpoint' **(Palghat, Horvath and Lodge, 2017, p. 5)**, while a third group might argue for an 'embodied cognition' perspective **(Crifaci et al., 2015)**.

7.4.3

CHALLENGES RELATED TO TRANSLATION

Learning has multiple realizations in the brain and about eight different learning systems in the brain have been identified **(Thomas, Ansari and Knowland, 2019)**. Although these learning systems all work together, they respond

Neuromyths, broadly, are overly simplified facts about the brain which lead to suggestions about learning in general as well as teaching practices that are incorrect.

differently over time and are impacted differently by training regimes or external factors such as motivation and emotional state. Because learning is a complex whole-person activity, EN will likely always require translation to become 'classroom-ready' knowledge **(Howard-Jones, 2010)**. For example, neuroscience techniques often show the additional neural activity associated with a particular task or condition. To an uninformed lay person the 'hot-spots' on these images could easily be interpreted as static and isolated functional units that are causative in nature, leading to a number of incorrect interpretations or neuromyths. In addition, if scientists have never taught a child with learning difficulties or a demotivated secondary school child, then it is unlikely they can understand how their findings may directly translate into practice. So even when animal models of air pollution on brain function are able to show a direct causal link between air pollution and cognitive abilities, for example memory abilities in rats **(Salvi et al., 2017)**, these findings and their consequences for education will still need to be translated into practice in a way that can be understood by policy-makers, practitioners, parents and students.

Translation therefore requires the sharing of a common language and an understanding of the research designs and limitations as well as an understanding of educational policies and practice. A lack of either of these may lead to oversimplification of complex mechanisms or neuromyths. Neuromyths, broadly, are overly simplified facts about the brain which lead to suggestions about learning in general as well as teaching practices that are incorrect. Neuromyths are commonplace in the general population, including among politicians and teachers **(Howard-Jones, 2014)**. What makes them neuromyths is that the claims are based in scientific facts that are oversimplifications of the data or are at best loosely based on neuroscience research **(Pasquinelli, 2012; Tardif, Doudin and Meylan, 2015)**. Their mythical status means they

Recent evidence suggests that awareness campaigns around neuromyths and provision of neuroeducational resources might improve endorsements of neuromyths.

are enduring: even when the claims are repeatedly shown to be false, they continue to circulate as scientifically based truths. These include claims such as: students use only 10 per cent of their brains; students have different learning styles (e.g. visual, auditory, kinaesthetic); water drinking enhances learning; sugary drinks increase distractibility; motor-perception exercises improve literacy skills; physical coordination exercises increase left–right brain integration **(Geake, 2008; Dekker et al., 2012)**.

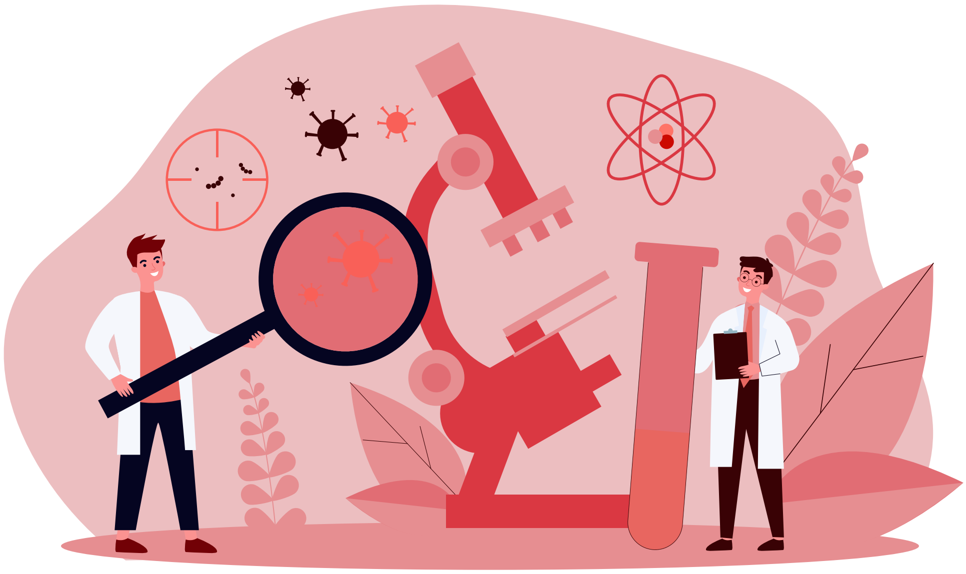
Among the most widely shared neuromyths are problematic claims about intelligence, brain structure, teaching, learning, human development, mind–body relationships, plasticity, memory, attention and language acquisition **(Tokuhama-Espinosa, 2018)**. Although they have been repeatedly debunked, neuromyths continue to exist around the world **(Gleichgerrcht et al., 2015; Hermosilla et al., 2016; Papadatou-Pastou, Haliouand Vlachos, 2017; Betts et al., 2019; Grospietsch and Mayer, 2020; Janati et al., 2020; van Dijk and Lane, 2020)** and in various educational subjects **(Bailey et al., 2018; Ruhaak and Cook, 2018; Grospietsch and Mayer, 2019)**. The presence of these myths requires continued vigilance **(Tokuhama-Espinosa, 2018; Grospietschand Mayer, 2020)**, not only because misleading claims undermine the science itself, but also because it can be damaging to the practice of education, including for student flourishing and for life more generally.

Recent evidence suggests that awareness campaigns around neuromyths and provision of neuroeducational resources might improve endorsements of neuromyths **(Gini et al., 2021)**. However, neuromyths are sometimes kept alive by the enthusiasm of policy-makers and stakeholders to produce quick fixes that shape policy and funding in education, as well as the drive for practitioners to use evidence-informed practice. Such research funding and mandates can skew towards 'quick-fix' solutions, relying more on simplified popular messaging than on more complex sets of evidence – including

... focusing on the first few years exclusively underplays the development that happens right through childhood and adolescence, and could potentially impact on opportunities to help people flourish.

evidence that is contrary to the proposed solution. For example, the incredible development during the early years and key findings in neuroscience about changes in the brain during this developmental period, have driven key political movements and investments related to supporting education during the early years (e.g. 'zero to three movement' in the USA and the Early Years Royal Foundation in the UK). Although there is no doubt that the early years are an extraordinary and vital part of child development, focusing on the first few years exclusively underplays the development that happens right through childhood and adolescence, and could potentially impact on opportunities to help people flourish. For example, during adolescence, there are dynamic changes in brain biology and similar processes to those in the womb and early development, such as over-production of cells and connections **(Giedd et al., 1999)**. Although there is enormous potential for development during this time, this potential is often overshadowed by an exclusive focus on the early years.

To prevent translation issues, a clear interdisciplinary and collaborative approach is required among all of the disciplines (biology, education, and the cognitive and developmental sciences) as well as the stakeholders involved (scientists, practitioners, public policy-makers and the public). This requires the building of a common language through a long-term continuing dialogue. To facilitate translation, an infrastructure is required that allows stakeholders to exchange ideas and knowledge, such as the International Mind, Brain and Education Society **(2004)**. However, such an infrastructure should also incorporate the establishment of large databases that include behavioural as well as biological information about child development and educational outcomes. Although there is mixed evidence regarding whether training in neuroscience can actually minimize the development of neuromyths **(Macdonald et al., 2017)**, providing teachers and stakeholders with



an understanding of EN as well as training in research designs informed by neuroscience and genetics would counteract misconceptions but also instill the scepticism that is needed to evaluate novel educational programmes as well as tools for teachers to provide evaluations of educational programmes **(Fischer et al., 2010; McMahon et al., 2019; Gini et al., 2021)**.

Better collaboration between practitioners and scientists would not only ensure that EN answers questions that are relevant to practitioners or for teachers to correctly implement EN-informed practice in an educational context, but would also allow greater insight into differences between schools and school contexts and how these impact on educational outcomes **(Hackman and Kraemer, 2020)**.

7.4 .4

CHALLENGE OF VALIDITY

Another challenge for EN to inform education policy and practice relates to the validity of the EN research conducted thus far. Most EN studies have been carried out in controlled laboratory conditions and this can sometimes lead to oversimplified theories and leave out processes that are critical to what makes us truly human. For example, research has shown that successful mathematical abilities rely on the

... several approaches have been used to improve the representativeness and therefore translatability of, for example, neuroimaging research.

interaction between a number of domain-specific (such as symbolic knowledge) and domain-general abilities **(Bartelet et al., 2014; Costa et al., 2018)**, in addition to factors such as teacher anxiety and abilities, student affective factors such as self-efficacy **(Kaskens et al., 2020)** and home-learning environment **(Mutaf-Yıldız et al., 2020)**. The neuroscience of numerical cognition has often focused on controlled experiments with neuropsychological patients and has shown that the intraparietal sulcus (IPS) area is a functional specialization for numerical presentation in the brain that independently predicts numerical quantity abilities in young children **(Ansari, 2015b)**. However, it is unclear from these studies whether the IPS region is prominently involved when children solve mathematical problems in the real world. Recent studies have shown that children's neural responses to real-world mathematics problems are better predictors of their mathematical success than neural responses in the lab **(Cantlonand Li, 2013)**.

Although it is clear that various ways of mapping the brain, particularly local regions, have given us powerful information about the brain's structure and function, the resultant images also have the inherent and standing weakness of being mis- or over-interpreted, especially in the media and by policy-makers and other stakeholders, including educational practitioners. These include assumptions that situate the authority and claims made on the basis of neuroimages. For example, there are assumptions around the cognitive elements themselves: remembering, attending, choosing; reading, speaking, observing; fearing, raging, nurturing. The assumption is that these are clear and distinct behaviours, and can be safely isolated – methodologically, epistemologically or ontologically. The assumption is not only that nature breaks clearly along these lines, but also that we can study and understand them in isolation. On these assumptions are built the claims that brain-imaging techniques and results give us accurate and clear knowledge

... wearable technologies or wearable sensing, can help transform our understanding of the brain through improved, more ecologically valid neuroscience.

of brain processes that correlate to these isolatable behaviours in the laboratory setting **(Almeida, 2019)**. However, different basic assumptions about reality – that what we take as real and isolatable depends on a figure/ground (focus/context) structure, means that isolation often fails to replicate the in situ behaviour, and that language often thins its embodied and relational complexity.

The EN community is increasingly aware of validity issues around laboratory-based research. Thus, several approaches have been used to improve the representativeness and therefore translatability of, for example, neuroimaging research **(van Atteveldt et al., 2018)**: (1) using more naturalistic stimuli and tasks to activate brain processes more closely related to realistic situations; (2) combining lab-based neuroimaging measurements with real-life variables and follow-up field studies; and (3) moving neuroimaging research out of the lab and into realistic settings, such as classrooms, using portable EEG or fNIRS devices.

EN is now developing new data-driven approaches for higher-order neural activity **(Cantlon and Li, 2013; van Atteveldt et al., 2018; Cantlon, 2020; Nastase, Goldstien and Hassan, 2020)**. Studies using data-driven approaches of neural responses during naturalistic tasks have shown that children have distinct responses which differ from adults **(Kersey et al., 2019)**. Other technological advances, such as wearable technologies or wearable sensing, can help transform our understanding of the brain through improved, more ecologically valid neuroscience **(Ward and Pinti, 2019)**.

In sum, the use of naturalistic tasks, new technologies to measure behaviour and brain activation, and new data-driven approaches allow observation of a broader range of neural patterns and functions. However, without strong theoretical explanations, there is a danger that patterns are observed that yield no understanding in the link between classroom behaviour and brain activation **(for further discussion see Cantlon, 2020)**.

... focus on improving educational outcomes through practices such as mindfulness training, which work to improve social and emotional skills and competencies necessary for childhood flourishing.

7.4 .5

CHALLENGE OF INCLUSION

The main goal of EN is to enhance the cognitive abilities of children. However, children differ in their abilities, prior knowledge, SES, cultural context, and racial or ethnic background. EN research that is narrowly focused on cognitive abilities can easily miss the larger picture of what works for whom, and how to address all the variability that constitutes student populations – this is a challenge of inclusion.

Further, although the overall goal of intervention studies is improving specific educational outcomes, approaches studying individual differences may remain focused on factors that limit a child's progress, rather than those that may advance outcomes. Both the brain and education are complex phenomena that are impacted by a large number of factors which interact with one another. However, other intervention studies based on EN focus on improving educational outcomes through practices such as mindfulness training, which work to improve social and emotional skills and competencies necessary for childhood flourishing, and changes in school start time based on findings from sleep and memory research, which work to improve the overall attentiveness of students.

Like research in other social sciences, EN thus far has been largely restricted to developed countries and to so-called WEIRD populations (Western, educated, industrialized, rich and democratic samples) **(Henrich, Heine and Norenzayan, 2010)**. These often-small convenience samples mean that EN currently cannot provide much meaningful insight into individual differences. In addition, it is likely that in less developed countries, social factors and environmental factors such as nutrition have a different or more important impact on educational outcomes. Therefore, not only should research extend

... science achievement is predicted by individual factors such as motivation in the two high earning countries, whilst in middle-income countries it is predicted by school factors (e.g. having sufficient resources).

to include developing countries, it should also focus on social and political factors that impact on educational outcomes. For example, Nieto and Ramos **(2015)** examined factors that affect science and reading achievements in both high-income countries and middle-income countries and found that science achievement is predicted by individual factors such as motivation in the two high earning countries, whilst in middle-income countries it is predicted by school factors (e.g. having sufficient resources). Similarly, reading abilities were also best predicted by school factors for all countries examined.

One promising solution to increase the validity of EN is the focus on population neuroscience **(Paus, 2010; Falk et al., 2013; Smith et al., 2015)**, with a greater emphasis on theory-relevant sampling. Since there are issues of optimal replicability with the small sample sizes of typical fMRI experiments **(Makel and Plucker, 2014; Turner et al., 2018)**, recently, several large-scale initiatives have emerged: the online OpenNeuro database **(Milham, 2012)** that contains task-based fMRI data **(Poldrack et al., 2013)**, the Neurovault database **(Gorgolewski et al., 2015)** that allows meta-analyses of fMRI data often using activation likelihood estimation (ALE), and NeuroSynth for automated synthesis of fMRI data **(Yarkoni et al., 2011)**. There are also large-scale fMRI data initiatives for autism **(Di Martino et al., 2014; Payakachat, Tilford and Ungar, 2016)**, dyslexia **(Lyytinen et al., 2015)** and healthy brain development **(The Baby Connectome Project (Howell et al., 2019) and The Lifespan Human Connectome Project in Ageing (Bookheimer et al., 2019)**. These efforts will provide a better understanding of how the brain changes over development, how these changes may relate to educational practice, and what social and political factors impact on EN.

Can EN improve 'living together' and inclusion? Neuroscience can help explain why some people with atypical brain structures (autism, ADHD) flourish whilst others do not. The social movement of neurodiversity, A curriculum developed under UDL aims 'to serve a diverse set of students with a wide range of sensory, motor, cognitive, affective and linguistic skills'.

which challenges the notion of easily categorizable boundaries of 'special educational needs and disabilities' (SEND) **(Lewis and Norwich, 2004; also see WG2-ch4)**, plays a role in inclusive education that is relevant to teaching and pedagogy and teacher training. The notion of neurodiversity highlights that there are individual differences in how the brain functions and the learning environment needs to accommodate all learners who encompass the entire spectrum of learning abilities, including those with special learning needs. For example, Universal Design for Learning (UDL) is framed within the field of neuroscience and educational technology. A curriculum developed under UDL aims 'to serve a diverse set of students with a wide range of sensory, motor, cognitive, affective and linguistic skills' **(Villoria and Fuentes, 2015, p. 2)**. Beyond UDL, teacher training and teaching instructions play an important role in accommodating functional diversity present in all classrooms **(Gobbo and Shmulsky, 2019; Aguilar, Melero and Perabá, 2020; Griffiths, 2020)**. This is probably where neuroscience can contribute the most.

7.4.6

ETHICAL CHALLENGES

Whilst numerous examples can be given of how EN might inform educational practice and policy, it is currently not yet clear what the ethical implications might be or how they should be addressed. Knowland **(2020)** describes a number of ethical factors to be considered by the field of EN. These include: weighing up the risks of any EN intervention compared to the benefits; examining carefully any individual differences in who benefits most from any EN-based interventions; and understanding how the different contexts in which the EN intervention takes place may impact on outcomes. For example, taking slow-acting prescription psychostimulants (e.g. Ritalin) may indeed improve the neuropsychological functioning of those with ADHD **(Boonstra et al., 2005)** as well as healthy young

Ethical challenges do not mean that EN cannot inform educational practice or that we should steer away from EN interventions.

adults **(Ilieva et al., 2015)**. Yet, these medications all have side-effects and taking medication may not only have direct physical negative side effects but may also lead to long-lasting changes in the prefrontal cortex of the brain with further consequences later in life **(Ilieva et al., 2015)**.

Further, in addition to questions about what works and when – for example, if early intervention is better, should infants be given medication, and other EN-based therapies? – there are ethical questions to be considered about how EN interventions can be seen as fair, across individual children, across schools, and across different countries. Studies across several cognitive fields (including reading and mathematics) have shown that low-performing children and those from low socio-economic backgrounds benefit most from educational interventions **(Dietrichson et al., 2017)**. However, this raises the ethical question: if provision of EN interventions will be provided selectively to a few, how will any treatment barriers be defined and by whom? As Knowland **(2020, p. 487)** points out: 'selective provision […] may result in differences in how children perceive their own academic success and, far from closing the gap, would create a new one driven by differential treatment, which may cause societal problems even greater than the ones the intervention seeks to solve'. Who benefits from EN's research, and how such benefits are distributed, are ethical questions of distributive justice.

Ethical challenges do not mean that EN cannot inform educational practice or that we should steer away from EN interventions. However, in order for EN to provide clear guidance on what works for whom, clear guidance on the goals of education need to be provided, including the question whether education should improve educational outcomes for all or for those who struggle only (e.g. 'leave no child behind' policy)? In sum, we need a better understanding of what we value about education and what we envision good education should provide.

7.5 Conclusions

The overall aim of this chapter has been to examine the broad contexts of and challenges for EN. By this we mean the social, cultural, political, ideological and conceptual contexts of EN as a research practice in its relation to education. In the background is the question of what role EN might play in

A twenty-first-century vision for neuroscience is one in which discoveries in neuroscience help contribute to human flourishing, broadly conceived.

advancing human flourishing as education's purpose **(developed in WG1)**. Human flourishing involves an emergent dynamic ethos connected to socio-emotional development; mental and physical health; and living together well politically, economically, socially and culturally. The lens of human flourishing takes us outside the school walls and into its social, cultural, economic and political contexts, which means also that EN is contextualized in all of those dimensions. Discussion of flourishing particularly brings to the foreground issues of inequality and oppression, which include the intersections of inequality along gender, racial, socioeconomic, religious and cultural dimensions **(WG2-ch4)**. What might EN contribute to both understanding, and dismantling, these savage inequalities and oppressions? How might EN studies of vulnerable populations – along various dimensions – give educators good information about the neural impacts of particular inequalities (e.g. the impact of oppressive poverty) on developing brains (persons)?

We focus on broad contexts not only because they impact EN's information for formal schooling, but also because the broad vision of human flourishing means that EN isn't only for schooling, but for something bigger. Although clearly it has a role of informing practices inside the classroom, we think that it would be fruitful to expand the idea of EN: EN should serve not only formal schooling but its societal contexts as well. Taking a broad human flourishing approach, rather than a narrow human capital approach, has implications for understanding both what EN is and what its scope might be. A twenty-first-century vision for neuroscience is one in which discoveries in neuroscience help contribute to human flourishing, broadly conceived.

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