NEUROSCIENCE AND EDUCATION

LOOKING OUT FOR THE FUTURE OF LEARNING

ANA LUIZA NEIVA AMARAL
LEONOR BEZERRA GUERRA

SESI
Brazilian Social Service for Industry
THE FUTURE OF WORKFORCE

2 WHAT IS NEUROSCIENCE?

This chapter makes clear what neuroscience is and why this knowledge field has gained so much importance since the last decade of the 20th century.

Neuroscience or neurosciences is an umbrella term coined – to the best of our knowledge – by Ralph Waldo Gerard, an American neurophysiologist from the University of Chicago in the 1950s. However, it was Francis Otto Schmitt, biophysicist, chief at the Biology Department at the Massachusetts Institute of Technology (MIT) that made the term famous in the 1960s[2]. He used the term 'neuroscience' to refer to an interdisciplinary knowledge field that studies the **nervous system.**

In 1962, Schmitt oversaw the creation of a Neurosciences Research Program (NRP) that gathered scientists from the USA and other countries with different backgrounds but interested in understanding how the **brain** controls behavior in general and the human mind, specifically. They regarded that understanding how the brain and mind worked was beyond the grasp of an individual or a group of researchers. To that effect, a joint effort from professionals from different knowledge areas would be necessary to explain mechanisms underlying learning, memory, motion control, emotional regulation, and other aspects of human behavior. Hence, theories for multilayered brain functioning - from molecules to behavior - could be formed by gathering specialists in different areas such as neuroanatomists, cytologists, physicists, neurochemists, physiologists, zoologists, pharmacologists, neurologists, psychologists. Researchers involved in the program regarded that only with such an interdisciplinary approach[3] to study the universe's most complex structure, significant knowledge breakthroughs in mind and behavior would be possible.

In 1963 the Neurosciences Research Program Bulletin, the official NRP journal, used the term 'neuroscience' and 'neuroscientists' to refer to researchers of different aspects of the nervous system. They organized scientific meetings to discuss important themes about the nervous system and published - journal aside - many books over the following 20 years. Their initiative contributed to establishing a new knowledge field that spurred other research groups: first in Germany, then in Russia and England[4], and in other countries.

2 Adelman, G. (2010). The Neurosciences Research Program at MIT and the beginning of the modern field of Neuroscience.
3 Sabbatini, R. M. E., & Cardoso, S. H. (2002). Interdisciplinarity in the neurosciences.
4 Rose, S. (2015). The art of medicine: 50 years of neuroscience.

This resulted in the pollination of neuroscientific research that attracted general public interest for brain, mind, and behavior. This interdisciplinarity, which proved essential to advance research in brain and mind, has been coined Network Neuroscience[5].

Neuroscience, also known as Neurosciences, is an interdisciplinary area of knowledge that studies the brain, the mind, and human behavior. It draws together many subareas or knowledge fields whose scope is to investigate the nervous system.

2.1 BRIEF HISTORY OF NEUROSCIENCE

Although neuroscience as an interdisciplinary knowledge area came about in the 1960s, both interest in the brain and the idea that behavior and **mental functions** were interrelated dated from much earlier[6].

The observation that brain traumas caused behavioral and perceptual alterations with loss of consciousness and memory has probably contributed to associations between brain and mind activity. Evidence for that dates back ages. Palaeontologic findings of prehistorical skulls with perforations made in life, also known as trepanations dating more than 10.000 years ago, showed that cavemen messed with the brain, mainly thinking that they could pull evil spirits away from the suffering body[7]. In ancient civilizations in Egypt, India, China, and Greece, the notion that our heart controlled mental processes was prevalent[8]. This idea still lingers in common-sense observations when we say that we know something ‘by heart’ for something stored in our memories. Such association, made long ago, is probably due to a faster, stronger heartbeat when expressing emotions. It happens as the **sympathetic autonomic nervous system,** part of the nervous system, takes over during emotion expression and acts on the heart, increasing heart rate and its force of contraction. A further example is the verb ‘record’ derived from the Latin *recordis* to mean reflowing through the heart. Despite neuroscientific evidence that the seat of emotional processing lies in the brain – not the heart – such expressions reveal the intrinsic relationship between memory and emotions. We will go over that in depth in chapter five.

5 Bassett, D., & Sporns, O. (2017). Network neuroscience.
6 Finger, S. (2001). *Origins of Neuroscience: A history of explorations into brain function.*
7 Cosenza, R. M. (2002). Espíritos, cérebros e mentes. A evolução histórica dos conceitos sobre a mente.
8 Castro, F. S., & Landeira-Fernandez, J. (2010). Alma, mente e cérebro na pré-história e nas primeiras civilizações humanas.

Over time, evidence of the brain as the fundamental seat for mental functions began to surface. The Edwin Smith papyrus, written around 1700 BCE (T.N.) and attributed to the Egyptian physician Imhotep, brings clinical brain and **spinal cord** injury accounts, relating lesions associated with motor and language alterations, loss of urinary control, and others[9]. As far as we know, this is the first account with descriptions of some nervous system structures and their association with other bodily functions.

In western culture, Alcmaeon of Crotona, Greece (500 BCE) was the first to relate the brain to mental functioning while dissecting some **nerves** – optic nerves included. He discovered that some sensory pathways ended in the brain. In his view, the different nerves transmitted information to the brain where each sensory modality had its neural territory.

Also in ancient Greece, Hippocrates (460-379 BCE) already believed that the brain was the seat for the mind. Plato (428-348 BCE) also regarded the brain as the seat for mental processes and responsible for controlling bodily functions. Aristotle (384-322 BCE) wrote about sleep but stood against his counterparts as he regarded the heart as the organ for emotions. Herophilus (335-280 BCE) dissected the **brain ventricles** and suggested that human intelligence sat in these cavities[10]. In ancient times, studying the brain and other structures within the skull – together known as the **encephalon** – was very hard as there was no tissue fixation. Without fixation, this structure presents a gelatinous consistency and easily deforms when manipulated. This might explain the interest some philosophers and physicians had in brain ventricles as the seat of the mind, according to Galeno (130-200).

From Renascence on, ideas about how the brain works and how it relates to mind and behavior got revisited by several scholars. Some ideas were, at given points, very different from what we know today[11]. These contributions – cornerstones in the history of neuroscience – can be accessed by an interesting timeline, the Milestones in Neuroscience Research[12], organized by the University of Washington in Seattle (USA). Even so, they represent a fraction of the dedication countless scholars have given to studying the nervous system across time[13].

Translator's Note: BCE stands for before the common (or current) era and has been widely adopted in academia for its non-partisan status.

9 van Middendorp, J. J. *et al.* (2010). The Edwin Smith papyrus: A clinical reappraisal of the oldest known document on spinal injuries. Stiefel, M. *et al.* (2006). The Edwin Smith papyrus: The birth of analytical thinking in medicine and otolaryngology.

10 Cosenza, R. M. (2002). Espíritos, cérebros e mentes. A evolução histórica dos conceitos sobre a mente.

11 Brown, R. E. (2019). Why study the history of Neuroscience?

12 Milestones in Neuroscience Research: https://faculty.washington.edu/chudler/hist.html.

13 Finger, S. (1994). *Origins of Neuroscience: A history of explorations into brain function.*

The development of histological techniques for nervous tissue fixing and staining at the end of the 19th century was a milestone for modern neuroscience as it enabled visualization and the resulting study of **neurons** – what became known as the **neuron doctrine**[14]. From then on, meaningful discoveries related to structural and functional aspects of the nervous system opened up research avenues for what we currently know in neuroscience.

Thereby, we know that the nervous system is composed of billions of neurons and **glial cells**, organized in many structures that are visible to the naked eye, such as nerves, spinal cord, **brain stem**, **cerebellum**, and the brain[15]. In each structure, different **neural circuits**, taken as groups of neurons interconnected by structures called **synapses** and glial cells, which are fundamental for the survival and functioning of neurons, can only be observed by using microscopic and electrophysiologic techniques.

Neurons got defined as cells with extensions – **axons** and **dendrites** – that get connected to other neurons through synapses. Neurons also connect with **sensory receptors**, skeletal muscles, glands, and other organs in the human body through nerves.

Neurons got to be known as cells that process and transmit information through electrochemical signaling. In other words, neurons are excitable cells that alter their chemical and electrical state when they are in contact with some form of energy in the environment, termed stimuli. Such stimuli can be electromagnetic (light), mechanical waves (sound), chemical (smell or taste), thermal (hot or cold), and mechanical (pressure, vibration, or touch). When stimuli reach the nerve cells, they cause alterations in the molecules of the cell membrane. This leads to a change in the chemical and electrical state of the neuron – termed **nerve impulse**. Some studies have shown that the nerve impulse generated by one neuron may be transmitted to another neuron by chemical substances – the **neurotransmitters** – at their connection site, the synapses.

In this fashion, we understood how the nervous system can record – by neuron activation – all the interactions one has with the environment. This neural activity generates mental functions and behaviors. Once activated, neurons can act on many body muscles and organs through the nerves. When this happens, there is movement, increased heart rate, bowel movement, hormone secretion, speech production, and other functions related to each structure regulated by the nervous system.

14 Yuste, R. (2015). From the neuron doctrine to neural networks.

15 Lent, R. (2010). *Cem bilhões de neurônios? Conceitos fundamentais de neurociência.*

We know that the nervous system receives and processes daily incoming stimuli via sensory organs – sound, images, smells, tastes, and tactile, thermal, visceral, proprioceptive and vestibule sensations – generating responses expressed by adaptive behaviors. These improve one's odds of survival and preservation. However, our nervous system also enables us to create and transform our surroundings. It is a very creative ability that explains humankind's fantastic evolution across time[16]. This adaptative and creative interaction with the world, nature, objects, people, and culture is essential for the developmental and learning processes[17] (T.N.).

Thus, all human behavior and mental function emerge from nervous system activity, chemical and electrical phenomena in diverse neuron populations forming **neural networks**. Functions related to cognition and emotions that are part of our everyday lives and social relationships – like teaching and learning; feeling and noticing; crying and laughing; sleeping and dreaming; wishing and getting frustrated; breathing and eating; speaking and moving; understanding, reasoning, and calculating; paying attention, remembering and forgetting; planning, judging and deciding; thinking and imagining; getting emotional, loving and taking care – are all behaviors that rely on the integrated workings of different structures in the nervous system, especially the brain.

The mind is the brain at work. The constant interaction between the nervous system and the environment we live in determines who we are, what we think and do. Interacting with the world, nature, objects, people, and culture is essential for human adaptation and creation.

Neuroscientists research the nervous system to understand how the 86 billion neurons enable motion, sleep, dreams, feelings, memory, attention, emotions, thoughts, decisions, and consciousness, among other aspects of the human mind and behavior. Likewise, they investigate what happens when the nervous system suffers alterations, such as paralysis, sensory or cognitive impairments, altered states of consciousness, mood and emotional changes related to neurological, neurodegenerative, psychiatric, and neurodevelopmental disorders[18]. Understanding how the nervous system works in physiological and pathological conditions enables interventions that can exponentiate

16 Fogarty, L. *et al.* (2015). Cultural evolutionary perspectives on creativity and human innovation.

17 Chiao, J. Y. (2018). Developmental aspects in cultural neuroscience.
Translator's Note: The box containing additional information on this topic in the original version had its content incorporated into the text in the English version for editing purposes.

18 Thompson, P. M. *et al.* (2020). ENIGMA and global neuroscience: A decade of large-scale studies of the brain in health and disease across more than 40 countries.

mental functioning and, in case of disease, the development of preventive measures, symptom reduction, and even cure in some cases[19].

The 20th century saw great strides and massive breakthroughs in our knowledge about nervous system development, structure, and function in physiological and pathologic conditions. They were made possible by novel research methods and techniques such as data digitalization, electrical brain activity recordings, brain areas visualizations (neuroimaging), molecular biology studies, and interfaces with the nervous systems (neurotechnology). Research on diverse aspects of the nervous system functioning - neuronal action potential, synaptic function, axon growth, sleep and awake states, emotions, language, logical and mathematical reasoning, attention, memory, learning, and stress - enabled a greater understanding of how the brain works. Taken together, they provide an understanding of how we operate[20].

A revision of the localizationist theory of brain function, i.e., each set of neurons in a given brain area has a function – led to what we currently know, that is, brain functioning is based on a connectionist model[21]. In such model, different mental functions relate not only to certain brain circuitry in a certain brain area but also to the integrated activity of neural circuits in different brain areas. Long axon bundles interconnect these areas creating functional neural networks[22]. Distinct neural networks are recruited simultaneously during the expression of behavior. For instance, when students write an essay, they recruit memories, convert their thoughts into words, make the necessary movement for writing, check if their writing is correct, evaluate whether they like the idea on paper, and modify it, if needed. In this process, neural networks related to memory, creativity, motion, vision, attention, performance control, and others spring into action. A network organization causes a brain area to act on the activity of another brain area. This is the reason why a teacher's comment - be it some praise or some information on the time remaining - may come to influence students' essay outcomes. Behavior gets generated by the activity of such neural networks comprising millions of neural circuits essential for information processing, both that stored in the brain and the information students receive at any moment[23].

Until the 1970s, we could only examine the brain by opening up the skull of patients with severe lesions or the deceased. Animal models, whose brains could be examined, were

19 Stein, D.J. *et al.* (2015). Global mental health and neuroscience: Potential synergies.
Erickson, K. I. *et al.* (2014). Health neuroscience: Defining a new field.

20 Lent, R. (2008). *Neurociência da mente e do comportamento.*

21 Mill, R. D. *et al.* (2017). From connectome to cognition: The search for mechanism in human functional brain networks.

22 Herbet, G., & Duffau, H. (2020). Revisiting the functional anatomy of the human brain: Toward a meta-networking theory of cerebral functions.

23 Lent, R. (2019). *O cérebro aprendiz: Neuroplasticidade e educação.*

– and remain so – insufficient for the investigation of the particulars of human behavior. With the development of neuroimaging techniques[24] (computerized tomography, functional magnetic resonance imaging, **tractography**, and **functional near-infrared spectroscopy – fNIRS**) allowed for registering brain activity before, during, and after certain stimuli, thus showing activation and connectivity of regions involved in different tasks. Today, fNIRS technology enables measuring the brain activity of people in motion. Hence, scientists can examine the human brain in real time and store information on students' brain functioning as behavior happens. This means that research for education is no longer constrained to laboratories. It can happen in classrooms with real students interacting and experiencing authentic learning situations.

Advances in neurotechnology[25]made possible a direct connection between technical components and the nervous system. Electrodes, computers, or intelligent prosthetics can record brain signals and translate them into technical command controls or manipulate brain activity by using electrical or optical stimuli. The human-machine interface brought intervention perspectives for diseases causing movement loss such as amyotrophic lateral sclerosis. Neurotechnology also allowed for an investigation of cognitive and emotional processes and enabled interventions for improved mental health and quality of life.

2.2 INVESTMENTS AND ADVANCES IN NEUROSCIENCE

The study of the nervous system has attracted huge investments and incentives since the 1990s. Former USA President George Bush's initiative to declare the Decade of the Brain[26] pushed the country to invest large sums in laboratories that investigated the nervous system. This has sped breakthroughs in neuroscience at the end of the 20th century[27] and over the first two decades of the 21st century[28]. The movement rooted in the USA spread over many countries and currently comprises thousands of neuroscientists and billions in investments[29]. This has stirred the current global revolution in an ever-increasing, multidisciplinary, ambitious effort[30].

24 Vasung, L. *et al.* (2019). Exploring early human brain development with structural and physiological neuroimaging.
Annavarapu, R. N. *et al.* (2019). Non-invasive imaging modalities to study neurodegenerative diseases of aging brain.
Balardin, J. B. *et al.* (2017). Imaging brain function with functional near-infrared spectroscopy in unconstrained environments.

25 Müller, O., & Rotter, S. (2017). Neurotechnology: Current developments and ethical issues.

26 Goldstein, M. (1994). Decade of the brain: An agenda for the nineties

27 Tandon, P. N. (2000). The decade of the brain: A brief review.
Volkow, N. D. *et al.* (2010). A decade after the Decade of the Brain.

28 Albus, J. S. *et al.* (2007). A proposal for a decade of the mind initiative.
Abbott, A. (2013). Neuroscience: Solving the brain.

29 Rosso, C. (2018). The funding spree for neuroscience startups.

30 Grillner, S. *et al.* (2016). Worldwide initiatives to advance brain research.
Yeung, A. W. K. *et al.* (2017). The changing landscape of neuroscience research, 2006–2015: A bibliometric study.

In the USA, the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative[31] got support from former President Barack Obama. The initiative encompasses federal agencies, foundations, institutes, universities, and industries. It aims at developing and applying innovative technologies for a dynamic comprehension of brain functioning, catapulting current knowledge about the human brain. The BRAIN supports discoveries related to brain alterations such as Alzheimer's and Parkinson's in depressions and traumatic brain injury.

The Human Connectome Project (HCP)[32] at the National Institutes of Health, in the USA, is building a map of neuronal connections (connectome) that showcases anatomical and functional connectivity of a healthy brain. In addition, it will yield data facilitating research on brain alterations in disorders such as dyslexia, autism, Alzheimer's, and schizophrenia.

In 2013, the European Commission kicked off the Human Brain Project (HBP)[33] via the funding program Future and Emerging Technologies program. HBP is building cutting-edge collaborative translational (scientific) research infrastructure based on information and communication technologies. This project will enable European researchers and technicians to advance their knowledge base in neuroscience, computation, medicine, and technology inspired by brain mechanisms such as artificial intelligence. Their goal is to translate basic research into medical applications for new brain-related diagnostics and therapies.

With incentives of this kind, many research centers for neuroscience development as well as networks among researchers have blossomed in many countries, including Brazil, which counts with 280 neuroscience research communities[34], registered at the National Council for Scientific and Technological Development (*Conselho Nacional de Desenvolvimento Científico e Tecnológico* - CNPq). They are in health and biology, education, modern languages, law, philosophy, anthropology, sociology, arts, communication, administration, architecture, computation, physics, and mathematics.

2.3 NEUROSCIENCE AND ITS CONTRIBUTIONS TO OTHER KNOWLEDGE FIELDS

As a result of investments made during the Decade of the Brain (1990-1999), vast scientific dissemination related to neuroscientific discoveries took place and turned this area into a very well-known and accessible knowledge base[35]. Neuroscience departed

31 BRAIN Initiative: https://www.braininitiative.org
32 Human Connectome Project: http://www.humanconnectomeproject.org/about/
33 Human Brain Project: https://www.humanbrainproject.eu/en/
34 CNPq: http://dgp.cnpq.br/dgp/faces/consulta/consulta_parametrizada.jsf
35 Illes, J. *et al.* (2010). Neurotalk: Improving the communication of neuroscience research.

from academic niches and became an all-interest arena for areas that deal with human behavior. It comes as no surprise that people got so interested in the topic. Neuroscience concerns our thoughts, who we are, how we operate, learn, change and live. It helps us understand life a little bit better, why we dream, why we like a place more than others, why we get angry, how we make decisions, how we get frustrated. It gives people the opportunity to know the brain so that they can care for their mental health[36].

Of note, in studying the bases of human behavior, neuroscience can contribute to the understanding of many aspects of other knowledge areas with different epistemologies not traditionally tied to knowing how the nervous system operates. Such areas did not rely on neuroscience for their knowledge base as well-rounded knowledge of the nervous system was not available at the time of their construction. As human behavior got explained, many knowledge fields – whose scope is not the study of the nervous system per se but that rely on human behavior – have come to consider neuroscientific discoveries as a source of scientific evidence for their theory and practice[37]. Some areas that count on neuroscience contributions are education, linguistics, philosophy, music, arts, marketing, economy, sociology, anthropology, law, ethics, to name a few.

By taking neuroscience as a new scientific perspective that constitutes the theoretical bases of other knowledge areas and their praxis, improvements in their knowledge base exponentiate Recovering the thought by E O. Wilson in the book *Consilience* (1998)[38] the knowledge to be developed by the human mind will inevitably spring from the cooperation of natural and human sciences.

Some areas like psychiatry and psychology[39] have already benefited from a greater understanding of the brain, behavior, and mental functions. Other areas have flirted with neuroscience but are yet to take better advantage of the evidence neuroscience can offer. Education is one of them. The next chapter focuses on the dialogue between neuroscience and education.

---

36 Erickson, K. I. *et al.* (2014). Health neuroscience: Defining a new field.

37 Kedia, G. *et al.* (2017). From the brain to the field: The applications of social neuroscience to economics, health and law.
Churchland, P. S., & Phil, B. (2008). The significance of neuroscience for philosophy.

38 Wilson, E. O. (1998). *Consilience: The unity of knowledge.*

39 Ross, D. A. *et al.* (2017). An integrated neuroscience perspective on formulation and treatment planning for posttraumatic stress disorder: An educational review.
Hyman, S. (2007). Can neuroscience be integrated into the DSM-V?