[Opinion Article]

Bridging the learning gaps to improve mentoring of doctoral students in cognitive neuroscience

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***Running title*:** teaching 21[st]-Century neuroscience skills

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Title: 95 characters with spaces.
Word count: Abstract: 206 words; Main text: 2300 words.

Keywords: cognitive neuroscience skills, research skills, education, interconnected learning, interdisciplinary learning, creativity, research ethics.

Abstract:

The exponential growth of neuroscience is resulting in the diversification of career opportunities outside of academia in both the public and private sectors. Yet, the current PhD model in cognitive neuroscience focuses mainly on academic research, where students are mentored by faculty with little experience in non-academic careers. Many fresh PhD graduates find themselves ill-equipped to meet non-academic industry demands that are increasingly transdisciplinary. This opinion article highlights the limitations of the current PhD model, as it moves students too early into highly specialized topics, without giving them adequate time to deepen their foundational knowledge across neuroscience, and to then use it in applied contexts. In the race to publish as frequently and as early as possible, learning gaps tend to appear and widen throughout the doctoral years, however, for graduates to possess the tools to adapt to wider settings these gaps need to be filled. We provide examples of some topics and approaches in cognitive neuroscience from our own doctoral program, which can be covered through formal courses and other e-learning platforms. These topics, when combined with mentorship by multiple faculty with diverse research expertise, can bridge the learning gaps while widening practical applications, and increase the employability potential of PhD students in various sectors.

Neuroscience holds the remarkable potential to improve health and society. We are entering an exciting era, with the emergence of new neuroscience-related trends that go beyond the medical, and into education, consumerism, and the justice system (Altimus et al., 2020). The continued growth of neuroscience will rely on novel transdisciplinary approaches, involving teams composed of psychologists, biologists, physicists, mathematicians, bioengineers, computer scientists, educationalists, and even philosophers and lawmakers. The growth of neuroscience is resulting in the expansion of career opportunities in both public and private sectors, across professions, including scientists, entrepreneurs, analysts, consultants, and intellectual property experts (Akil et al., 2016). With this shift and an increasing numbers of PhD students in the cognitive neurosciences, one key challenge is to address whether current programs are preparing doctoral students to meet the present and future needs of these diverse careers. Here, we aim to highlight some learning gaps in how PhD students in the cognitive neurosciences are typically mentored, and to propose a set of key topics and approaches that can bridge those learning gaps, along with the academic to the applied.

Cognitive neuroscience is a dynamic field of research that aims to reveal the mechanisms responsible for how we think, feel, and act. This relies on the integration of behavioral design and measurement with various cutting-edge approaches to record and manipulate on-going brain activity. Many PhD programs offered by various universities across the world, include in-depth training in behavioral, neuroscientific, and computational methods. However, our experience with some recent PhD graduates, revealed some noticeable learning gaps that may hinder their ability to take-on new topics and challenges. To illustrate this problem, we describe below the examples of two recent PhD-graduates, A and B, from our previous interactions with real cases.

PhD holder A was interested in the functional properties of a specific brain region: the middle part of the superior temporal sulcus. They had a deep knowledge of the functional roles of this region, in particular in the left hemisphere. To a general audience and for nonexpert colleagues, this PhD holder was viewed as an expert in brain function. However, as soon as effects of interest moved 2-3 cm away from this specific brain location, holder A felt lost in unknown anatomical territory. This of course, was an unsurprising outcome of the way in which (hyper)specialization is practiced in many laboratories. The importance of expertise is not being questioned, as it allows for deeper explorations in given areas; we are however pointing out that this (hyper)specialization comes at the price of multidisciplinary interactions, where junior investigators become less likely to expand to near topics of broader impact, which would carry translational potential.

PhD holder B was interested in assessing functional brain connectivity with neuroimaging techniques. Although they had deep knowledge of how to statistically assess whole-brain functional connectivity, there was an evident lack of understanding of how exactly regions communicate among themselves, and of the type of information conveyed. For instance, holder B was unable to describe basic mechanisms of synaptic transmission and plasticity, or to name some of the most-widely known neurotransmitters. This lack of knowledge about micro-level mechanistic explanations of connectivity limited holder B's ability to create accurate and useful connectivity-based models of functional integration or brain disorders.

Many examples can be presented, but the point here, is the need to re-think how current doctoral studies are undertaken in many laboratories (Taylor, 2011). Basic research experience is listed as a highly sought skill by universities selecting potential candidates for a given PhD program (Boyette-Davis, 2018). After assigning a supervisor/advisor (Barres, 2013), the PhD student usually continues within the research interests of the supervisor. At times however, the PhD student is too soon directed towards highly specialized topics or projects, before the student has had the time to experience wider foundations of cognition, anatomy, and behavior. In the race to publish as early and as frequently as possible, this type of PhD experience turns the student into an assistant-like technician, executing as many experiments as possible, as requested by the supervisor, while concurrently dealing with the frustrations of training and work–life balance (Woolston, 2019). We call for a re-thinking of how PhD students are trained at the conceptual and methodological levels, especially in doctoral programs with no required courses. Doctoral students may come from diverse disciplines and backgrounds, for instance with a background in psychology, biology, math or physics, and their success in interdisciplinary neuroscience programs requires strong collaboration among faculty (Holley, 2009). Doctoral students can learn by 'doing' research and reading literature, but this model is no longer up to the challenges of keeping pace with the ever-growing advances in cognitive neuroscience, its literature, and its applications.

Specifically, some topics that could bridge the learning gaps should be covered as part of formal courses, workshops, and seminars, as opposed to relying solely on informal sessions. Informal journal-club or laboratory meetings are valuable for certain discussions, but exposure to varied topics within a formal setting, can help PhD students broaden their knowledge, borrow concepts and methods from other fields, push their ability to synthesize multidisciplinary links, and encourage translational potential and applications to wider domains. Formal courses can be delivered in blended modes, in the light of the current expansion of (virtual) e-learning platforms that can offer synchronous or asynchronous online learning opportunities in a wide range of neuroscience topics. Below, we provide examples of some topics and approaches from our own doctoral program, which consists of developing foundations in cognitive neuroscience with applications in education; our student body consists primarily of students with a background in education and some exposure to scientific areas. The examples may seem highly specific to some or mundane to others, but together, the topics and approaches provide the foundations that offer students the opportunity to build a holistic view of brain-behavior and body system. This approach of addressing specializations that appear less essential to the overall program, support the ability to make extensions.

The peripheral nervous system. Brain processes give meaning to external sensory stimuli, with neurons projecting to the furthest reaches of the body, collecting input and responding to the environment. It is important to know how physical properties of external stimuli are transformed via receptors into electrical signals and conducted between distal and proximal nervous systems. Knowing the main circuitry of sensory systems from the periphery to the central nervous system helps students understand how sensory information is encoded, transmitted, and modulated before reaching the cortex. In practical contexts, it can give students a better understanding of sensory function or of sensory processing differences.

Behavior and measurement. Students should have a sense of how to measure a given behavior or mental process, and of what the main advantages and limitations of each measure are (e.g., reaction time, accuracy, sensitivity, prediction, error, adjustment, learning, adaptation, anticipation, etc.). These measures are indicators of the behavioral output of the brain as a system and can provide insight on how different tasks, stimuli, and modalities impact brain processes. This point may seem expected, however, numerous student experiences in neuroscience involve working exclusively on brain-imaging data sets, without deep understanding of the assumptions, implications, and limitations of the collected data.

Cognition beyond the cerebrum. There is more to the brain than its cortex. Students should have sufficient knowledge of the anatomy and role(s) of deep brain structures, the cerebellum, brain stem, and spinal cord. For instance, it is not unusual to see PhD students with limited knowledge on how information is encoded in different thalamic nuclei or how multimodal information is integrated at the level of the midbrain. Knowledge of autonomic, endocrine, and visceral functions are no less important than other more visible functions, such as motor and sensory processes, as they interact with cognitive processes in various ways. In applied contexts, this can be useful for understanding influences of health on cognitive function.

White matter connections. Interactions among regions are key to understanding how processes are sustained by different brain networks and pathways. They are also critical in modelling brain disorders and atypicalities. Understanding the anatomy of major white matter tracts, callosal connections, and the main circuits involving deep structures, is necessary to many anatomical models of brain systems including perception, memory, cognition, language, attention, reward, affection and action. In applied settings, this can be useful to explain outcome and predict recovery in clinical populations with diverse neurological or mental disorders.

Logic and Design. Logic is commonly overlooked in the curriculum of many PhD programs. It is not unusual to see junior researchers struggling with accurate formulation of a valid conditional statement, a key concept in understanding direction of inference, mediation, and causality. A sound background in logic will help students to accurately formulate their hypotheses, their predictions, and their research designs, along with learning to appreciate the advantages and limitations of reverse inference. This is useful for comprehending the direction (coding vs. decoding) of the numerous intricate relationships between behavior, brain structure, and brain function, and how best to evaluate these functions and relationships, according to research goals.

Neurotransmitters. Action potentials and communication at the level of the synapse are useful in understanding how neuronal circuitry works to sustain a given process. Brain function cannot be fully understood without considering neurotransmitters in the equation; functions include emotion, coordination, control, reward, attention, memory, learning processes, and more. Many atypical processes and impairments can be explained by dysfunctional neurotransmitter mechanisms in the brain. Such neurotransmitters are key to studying transmission and modulation of neural information at the synaptic level. In applied settings, this is useful for having a better grasp on how medication, deficiencies, and nutrition, could influence brain function and behavior. This understanding is also important to the current climate of commercial brain activity devices to monitor mediation, sleep, and more.

Computational and mathematical skills. Many advanced computational tools used in cognitive neuroscience help researchers analyze complex data without deep mathematical and computational background. However, the increasing amount and complexity of neuroscientific data often lead to researchers developing their own custom analysis procedures and programming codes to fully appreciate the implications of their data. While possessing the full scope of programming and mathematical knowledge may not be necessary, developing some specific and advanced skills would give student researchers the ability to handle diverse research designs and data structures varying from study to study. These skills can extend to any applied context where analytics are needed.

Genetics and Epigenetics. With the sequencing of the human genome and its genetic variants (genetics), there is a growing sophistication in understanding variations in behavior, patterns of brain activity, in the effects of drugs (medication), and in the interactions with atypicalities. In addition, environmental interactions with genetics (epigenetic mechanisms) affect physiology, behavior, and brain function. A grasp of these mechanisms allows for a better understanding of the possibilities and limitations offered by environmental manipulation (whether at the physiological or behavioral levels) on function and developmental considerations.

Impact - Translation, Practical Applications, and Community Outreach. Cognitive neuroscience is a highly technical field that carries extensive implications for humans and society. With the growth of neuroscience into various fields, its real-world meaning and effects need to be addressed. When practical considerations are integrated as part of their formal learning, students are consistently challenged to consider the impact of neuroscience for various communities – from expert to general, which in turn allows them to think of the implications of research beyond the immediate result. This iterative process is valuable not only for the implications of advances in neuroscience, but also for gaining a better understanding of basic mechanisms and functions of brain and behavior, along with potentially influencing experimental design. In addition, students learn flexibility in communication, to be able to interact with experts in their fields, along with general audiences. When students experience the opportunity to reach out to communities and reflect on their learning (Fang et al., 2022), they see the possible implications and impact of their work beyond scholarly contribution, and they begin to think differently when considering research. In addition, students experiencing community involvement during their studies, are more likely to give back to their communities (Barber et al., 2013), or be involved in community activities (Bryer et al., 2019) and volunteerism (Metz and Youniss, 2005).

The list of examples above is not exhaustive, but it provides a foundation that addresses the learning gaps in doctoral studies in the cognitive neurosciences. This can be combined with other professional development opportunities in the domains of communication, teaching, public outreach, ethics, collaboration, and leadership (Ullrich et al., 2014). Space and opportunities for engagement and interactions with postdoctoral fellows and senior graduate students can also sustain students in developing their skills further (Feldon et al., 2019). We call upon developers of doctoral programs to widen the curriculum, by encompassing broader inter-disciplinary topics that could create opportunities for different careers (Bear and Skorton, 2019); for example, many psychology programs require a minimum exposure to various areas in addition to the expertise gained through the student's specific work and laboratory. Indeed, there is a growing number of neuroscience PhD students opting for careers outside of academic research, even though they have been mentored by faculty with no experience in non-academic careers (Akil et al., 2016). Emerging trends in neuroscience stress the importance of fostering cross-training and cross-disciplinary science (Latimer et al., 2019; Nishi et al., 2016), in addition to strengthening experimental, analytical and communication skills. In addition, mentorship by supervisors with dissimilar research interests is valuable, as the future success of PhD students can be strongly associated with training by mentors of diverse expertise (Lienard et al., 2018). The ability of PhD students to integrate expertise from different mentors and areas would be augmented by filling-in gaps in their training and learning. Some of the key topics highlighted above are strong candidates for this comprehensive approach, which will help to form and retain talented PhD students, and ensure a bright future for cognitive neuroscience to serve the growing needs of various sectors, from health to education.

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