OPINION
Teaching Neuroanatomy Through a Historical Context

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Using data from a series of studies conducted by the authors, this opinion paper examines some of the current ethical controversies and resources issues currently faced by a variety of institutions in the approaches to teaching neuroanatomy. This paper argues that an alternative pedagogical approach, teaching undergraduate neuroscience using a historical context-based perspective, may address and perhaps ameliorate some of those ethical controversies and resource constraints. Additionally, this pedagogical approach may be a better *match-to-sample* tool for delivering the neuroanatomy curriculum to an increasingly diverse population of undergraduate students. Moreover, we argue that this approach enhances both individual student learning outcomes and student retention, and may ultimately produce better-trained future professionals in the neurosciences. This historical context-based approach is being used by few faculty scattered across the country, but in most cases, it is limited to a small part of the overall curriculum delivery (i.e., a few lectures), and typically is not a coherent perspective across the course. At the conclusion of this opinion paper, we offer some teaching resources for faculty interested in adapting this integrative approach to their current neuroanatomy curriculum. We envision that some of these examples will be instrumental in creating an educational dialogue about using historical contexts to teach undergraduate neuroanatomy courses.

Undergraduate universities must consistently update their curricula to keep pace with the rapid advances in the neurosciences. Neuroanatomy, specifically connecting structure-to-function, is the common denominator across the integrative neuroscience disciplines. It is central to understanding and conceptually bridging specialized areas such as neurobiology, neuropsychology, cognitive and behavioral neuroscience, to name a few. Therefore, students must develop a solid foundation in fundamental neuroanatomy before they can acquire and comprehend more advanced concepts. However, delivering a rigorous, connected, and integrated neuroanatomy curriculum at the undergraduate level is a challenge. Private universities can meet this challenge since they have better funding and resources to provide hands-on training through hospitals and cadaver dissection labs, thereby enriching their undergraduate neuroanatomy curricula. Such options and resources typically do not exist for smaller 2- and 4-year public undergraduate institutions (PUIs), which continue to face increasingly draconian budget cuts. Thus, the opposing forces of needing to continually enrich the neuroanatomy curriculum in the face of dwindling resources is a serious challenge for PUIs and smaller colleges, especially those without graduate programs.

For a deeper understanding of the issue of teaching neuroanatomy at the undergraduate level, we conducted a survey through the Faculty for Undergraduate Neuroscience (FUN) listserv from 2016-2017 and received anonymous responses from 36 universities (33.3% were PUIs and 69.4% were private universities). The faculty from both PUIs and private universities largely delivered neuroanatomy curricula as an introductory/foundational course (55.6%) that was taught to lower-(44.4%) and upper-(55.6%) division students. Interestingly, of the universities examined, 25.7% required no neuroanatomy pre-requisites for their undergraduate students, whereas others had the following neuroanatomy pre-requisites: English proficiency (11.4%), math proficiency (17.1%), introductory biology (60%), introductory chemistry (20%), introductory psychology (34.3%), and anatomy and physiology (22.9%). Thus, nearly one-fourth of this sample required no pre-requisites, while another one-fourth of the universities required English and math proficiencies. This begs the question: *How prepared are undergraduate students if they enter a neuroanatomy course, or an introductory biology, chemistry, and psychology course for that matter, without establishing the core writing and math skills essential to understanding and building a foundation within the sciences?* This lack of uniform pre-requisites for undergraduate neuroanatomy students may be addressed by teaching historical vignettes of neuroanatomy to facilitate students in associating structure-function relationships which can be easily learned and do not necessitate math or language pre-requisites.

Remarkably, PUIs offered a range of 2-4 lectures on neuroanatomy in their curriculum, while private university offerings ranged from 1-5 lectures, with the majority being from 3-5. Moreover, the survey revealed that PUIs were provided with the following neuroanatomy laboratory budgets: \$1K (28.6%), \$2-5K (2.9%), and > \$6K (0%). In contrast, private universities had budgets of \$1K (51.4%), \$2-5K (11.4%), \$6-10K (55.7%), and none above \$10K. This confirms our earlier assertion that private universities have more resources to teach neuroanatomy curricula than do PUIs. Of the universities surveyed (four PUI's and five private universities), one-fifth (22.2%) had programs which used human cadavers in their neuroanatomy curriculum to teach neuroanatomy at the undergraduate level. However, both PUIs and private universities indicated they would rather use alternative teaching methods (i.e., virtual laboratories to teach neuroanatomy), since one-fifth of the institutions (22.2%) reported significant issues with sourcing, storage, and disposal, as well as over two-thirds (69.4%) reported unsustainable funding demands for maintenance of human cadaver labs.

Thus, PUIs must proactively engage in the discussion of the necessary redesign of the neuroanatomy curriculum in order to maintain equitable rigor, in the context of limited (or even shrinking) resources. While there is considerable debate regarding which pedagogical methods are most appropriate to teach undergraduate neuroanatomy, many suggestions for redesign fail to balance the dual challenges of constricted resources and curriculum enrichment. This paper argues that teaching neuroanatomy from a historical context is an underutilized pedagogical approach, which may address keeping pace with advancements in the neurosciences, in the context of limited resources. We argue that teaching neuroanatomy from a historical context is a timely approach which may ameliorate the low resources and static financial support available to PUIs.

Challenges in Teaching Neuroanatomy Effectively: Non-Traditional Student Learning Outcomes

Historically, (neuro)anatomy with dissections was taught only in medical, graduate, or professional schools with cadaver labs (e.g., the classical anatomical amphitheater in Archiginnasio, Bologna in the 1930s (Ferrari, 1987). Today, traditional neuroanatomy is taught at the undergraduate level as lecture or a laboratory course that may or may not have dissections, based on resource availability. Educational advertising from institutions providing premedical undergraduate programs with cadaver labs claim that this approach increases medical school acceptance rates for their undergraduate students. This claim is debatable since medical schools may prefer a specific approach to teaching (neuro)anatomy to dovetail with more advanced, related learning later in medical school.

More significantly, however, students may be negatively impacted by cadaver dissection experiences. Medical schools describe cadaver dissection as a “rite-of-passage,” and approximately 5-10% of first year medical students engaged in cadaver dissections experience transient symptoms of Post-Traumatic Stress Disorder (PTSD) (Bergeron, 2005). The psychological effects of teaching cadaver labs on undergraduate students and related ethical concerns are still hotly debated. While 77.8% of both the PUIs and private universities surveyed had a consensus indicating that hands-on dissections were essential for teaching neuroanatomy to undergraduate students, our survey revealed that 11.1% of undergraduate faculty had student ethical and psychological concerns with teaching cadaver labs and 13.9% had personal ethical and psychological concerns. It is important to note that these data are within range of earlier reports by Bergeron (2005). This nexus of effective pedagogy, psychological, and ethical concerns is the heart of the conflict. *Does this mean that when teaching undergraduate neuroanatomy dissections, we should use more cadavers that are human and fewer that are animals, fewer cadavers that are human and more that are animals, or neither?*

Further, the last 20 years has seen a rapid growth in neuroscience curricula and programs across the nation paralleling a change in the student population taking undergraduate neuroscience courses. Students taking neuroanatomy courses are increasingly more likely to be both biology and psychology majors (Ramos et al., 2011). These data indicate that there is a new mixture of non-traditional students enrolling in neuroanatomy courses who may not pursue the more traditional medical and Allied Health careers, but may choose to work in professional fields related to psychosocial services and research (i.e., both basic and clinical). Thus, faculty teaching undergraduate neuroanatomy courses now face the following challenges in providing students with a well-established foundation: 1) not all students are pre-med, 2) students may enroll into neuroanatomy classes lacking the prerequisite knowledge-base, 3) courses are entirely neuroanatomical or constrained by a few weekly lectures, 4) courses may be laboratory or lecture, and 5) institutionally, there may be limited or no resources to enhance the quality of the curriculum. These challenges require neuroscience faculty to carefully assess their university situation and thoughtfully redesign their neuroanatomy curriculum.

Examining the Issues of Teaching Neuroanatomy: Cadaver Laboratories and Ethical Concerns

Undergraduate neuroanatomy laboratories commonly conduct cadaver dissections using rats, fetal pigs, and juvenile cats. Sheep brains outside of a cadaver are also utilized. From the student’s perspective, both the above and human cadaver labs are problematic. Both situations raise issues for students concerned about animal rights and ethical concerns. In our experience, students concerned about animal rights or other ethical issues are less likely to enroll in or participate in lab-based class components, and are often verbally disruptive in the lecture/discussion components of those classes when they do. This follows from data in our own biopsychology classes which cover neuroanatomy without cadavers and we find a trend of 5-12% of students with these concerns. Alternatively, in lecture formats with neuroanatomical imagery presenting clinical conditions these same students engage more freely in discussion and exploration. We postulate that this is due to the perception of a clinical video as being more “humane,” and actual dissections as inherently “inhumane.” It is our opinion that for the new mixture of non-traditional undergraduate students taking such interdisciplinary courses at both lower- and upper-division levels, lecture-demo formats, virtual laboratories, textbook assigned readings, and articles on the historical context of neuroanatomy may have an advantage over purely lab-based formats based solely on the perception of the ethics of the format (Neuwirth et al., 2018).

Lastly, human cadaver labs are expensive propositions for both PUIs and private university undergraduate neuroscience programs to consider. As of 2012, only 3% of colleges reported having access to human cadaver labs (~145 Association of American Medical accredited colleges vs. ~4,726 degree granting institutions, NCES, 2012). Further, increased human cadaver demand from undergraduate universities may create shortages for supplying medical schools (Bushey, 2013).

In summary: human cadaver labs on the surface may offer “premiere” learning opportunities for undergraduate students. However, recent research shows that undergraduate neuroanatomy classes increasingly are more likely to have non-traditional students seeking careers directed towards areas other than traditional medicine. These non-traditional students are increasingly more likely to raise ethical and psychological concerns about animal (and human) dissection. Thus, we think that without compelling evidence of the efficacy of human cadaver labs in increasing student-learning outcomes, PUI's, already under acute financial constraints, should not commit precious resources to funding human cadaver labs. Faculty teaching undergraduate human cadaver labs may want to re-assess their curriculum in light of current ethical controversies, and also to avoid resistance and potential repercussions from medical and other professional schools. Additionally, faculty teaching undergraduate neuroanatomy lectures without a lab may want to continue to assess and adopt other pedagogical methods for their curriculum, rather than moving in the direction of human cadaver labs or animal dissection.

Which Neuroanatomy Pedagogical Approach is Most Appropriate for Teaching Neuroanatomy?

A number of alternative pedagogical approaches have been suggested to bridge this "gap" in teaching the structure-function relationships of neuroanatomy at the undergraduate level. Some of these pedagogical approaches include, but are not limited to: equivalence-based instruction, i.e., teaching a functional connection between two different stimuli; brain picture and structure name (Pytte and Fienup, 2012); using case studies (Kennedy, 2013); applying food dissections to teach terminology and positional axis (Watson, 2015); using computer programs to teach sheep brain anatomy (Grisham, 2006); using the Allen Brain Explorer with Brain Atlas (Jenks, 2009); promoting information competency (Freberg and Brosnan-Watters, 2005); implementing a literature-based review course on current research topics to enhance writing (Williard and Brasier, 2014); writing in neuroscience (Adams, 2011); and teaching dual formats using both neuroanatomy and neurophysiology (Estes, 2007). Altogether, each of the above approaches attempt to address the gap in teaching structure-function relationships without a dissection-based laboratory. However, none of them adequately address the structure-function connectivity issue as such issues are either too abstract, intrinsically complex, or actually complicated by the new technologies themselves. This issue can be illustrated by examining one of these approaches. Salomon et al. (2015) evaluated a multiple choice exam assessment that targeted student understanding of core concepts in neuroscience. In their neuroanatomy section, they used questions such as the one below:

> *"The postcentral gyrus receives ______ information, while the precentral gyrus has ______ function. (A: Somatosensory; motor)."*

This question requires a student to integrate an understanding of axis, brain region, and structure-function relationships in order to be able to compare and contrast them. In the Saloman et al. (2015) study, queries related to brain area groupings and answerable by simply stating brain areas, or identifications of what cell layers do or do not belong in a particular brain region, were consistently answered correctly at, or above, the 82% level. In contrast, queries that required integration of area-functional relationships were correctly answered by only 68% of the life science majors and 72% of the non-life science majors. These data point to a clear issue: students have difficulty integrating fundamental neuroanatomical concepts with structure-function relationships, and non-traditional neuroanatomy students may be at a further disadvantage. This is detrimental to the establishment of a firm neuroanatomy foundation in teaching the next generation of neuroscience undergraduate students, warranting further investigation.

Additionally, partial neuroanatomy courses constrained to a duration of 1-2 weeks may be overwhelming, lose student attention, fail to provide sufficient redundancy for adequate learning, and therefore may inherently incur a disconnect in structure-function learning. Even attempts at developing "course clusters" as part of a curriculum, are still faced with reduced student structure-function learning (Michael et al., 2009).

Establishing a Concrete Neuroscience Foundation: Teaching the Historical Context of Neuroanatomy

Along with the ethical and psychological issues raised earlier, an additional factor needs consideration. PUIs and smaller colleges often have more ethnically diverse student populations than do private universities, and this, too, necessitates different pedagogical approaches in the delivery of the curriculum. This assertion is supported by data from a recent study we conducted (see Mukherji et al., 2017; Neuwirth et al., 2018). The study, utilizing an online anonymous surveyed biopsychology students (N = 75) to assess learning of the same neuroanatomy curriculum across two PUIs. One university [College of Staten Island-CUNY n = 44] had 38.6% ethnic diversity, while the other [SUNY-Old Westbury n = 31] had a remarkable 77.4% ethnic diversity within their biopsychology classroom. While ethnic and non-ethnic student groups reported markedly different learning preferences/styles, both student groups were similar in one respect. Both groups were nearly equal in their preference in their ranking articles using historical contexts over learning through the textbook, lecture discussions, and virtual laboratory assignments (Neuwirth et al., 2018). Given the reality of the academic achievement gap in undergraduate education, identifying ways to stimulate the interests of students based on their learning/preferences/styles is an important factor in addressing the persistent disparities in educational attainment. That nearly ***all*** our students in neuroanatomy classes preferred historical-context articles became the impetus for this paper. We argue that differential student learning preferences may be a significant contributing factor in current student achievement disparities in the sciences. If left unaddressed, this lack of fit between curriculum delivery and student learning preferences may inadvertently maintain current academic achievement disparities.

Teaching neuroanatomy from a historical context is rarely discussed. We argue that it is a powerful and underutilized pedagogical method. The efficacy of narrative techniques in educational settings is pervasive, well-documented and need not be repeated here. However, we mostly accept their efficacy in the teaching and learning of young children during their early educational years, and the use of case histories, critical incidents, and simulations are both widely used and demonstrated to be effective for adult learners in colleges and universities today (see Taylor et al., 2000). Stories are remembered because they are engaging, contextual rather than abstract, provide scaffolding and, therefore, promote student learning via activation of multiple connectivity and retrieval pathways. Teaching the historical context of the discovery of neuroanatomical structures and functions provide precisely those same learning advantages. In an era of rapid advances in the field of neuroanatomy produced by the development of sophisticated technologies, we are tempted to focus learning more on techniques, tools, and applications in our delivery of the curriculum, and less on the history of how and why these tools came about, and/or even why we continue to seek advancements in the neurosciences. For example, the historical associativity of narratives has allowed generations of students to vividly remember Pavlov, his dog, and thereby the principles of classical conditioning as a lasting “story” connection.

Further, teaching neuroanatomy from a historical context may be more pedagogically useful than laboratory dissections and other previously mentioned pedagogical approaches, because it provides contextual structure-function relationships. Today’s undergraduate neuroanatomy classes are often taught without a historical context despite the fact that there is an abundant literature available for developing such curricula through many resources written by Larry W. Swanson. The extent to which today’s students are learning neuroscience devoid of any historical context places them at a disadvantage and may further diminish their potential for translating educational outcomes beyond the classroom. We provide the following arguments suggesting that the history of neuroanatomy can serve as a strong tether, bridging very rich content that enhances structure-function relationships and supports student-learning outcomes without additional resources. This methodology may also ameliorate some of the resource and ethical challenges faced by PUIs and Private universities today.

Our survey revealed that more than 60% of faculty surveyed reported that a historical context would be effective for teaching. Thus, there appears to be an under-documented group of faculty scattered across the nation that have been using historical vignettes to teach their undergraduate students and find it effective. For those who may want to try this approach, we offer an outline of neuroscience resources that we use to teach neuroanatomy through a historical context below with their accompanying references. 1). Neuroanatomy can be taught through a historical context: explicitly laying out the origins of medical science beginning with animal dissections, to barber surgeons working on human corpses, soldiers, and then patients (Robinson, 1984; Lambert and Kinsley, 2011). 2) This can be aptly followed by architectural body plans to overlay structure-function relationships which reinforce comprehension and integration. Swanson’s (2000) article, *What is the Brain?,* is the best compilation of neuroanatomical history in a single concise short article that is easily processed by undergraduates. Swanson (2012) later sets a more enriched approach to understanding how the brain’s architecture sets up the basic plan of an electro-chemical organism. This allows students to grasp the stimulus-response functions of the simple unicellular organisms and hydra with the most primitive nervous systems to begin to appreciate the more complex cellular structures and topology, neural networks, coordinating systems, and volition in mammals. 3) Students can then integrate the neural architecture through anatomical principles offered by Angevine and Cotman (1981), which historically provides a more comprehensive understanding of structure-function relationships and organization than many other neuroanatomy texts. This text’s introductory chapters lay out the ubiquity, unity, centralization, structural specialization, precision, and plasticity of the nervous system. These chapters describe the purposefulness of neural components, chemical coding, and metabolic demands of the nervous system. 4) Building from here, utilizing a context-specific approach and historical links, students can then integrate their understanding of more complex neural developmental disorders (congenital or acquired). *Clinical Neuroscience: Psychopathology and the Brain* (Lambert and Kinsley, 2011) is a text which provides a series of focused, well-controlled presentations of clinical syndromes, embedded in vignettes of the historical context of the field’s discoveries. This model of presentation is deeply integrative and provides the learner with a complete picture of neuroanatomy.

In our own experience, we have taught every neuroanatomy component of our curriculum through the lens of historical vignettes. We make students aware of: 1) who created and invented which technique and why, in their historical context, they did so, 2) how ideas from other disciplines were borrowed to maximize the goals of neuroscience establishing early integrative and cross-disciplinary learning, 3) how scientists could be so resourceful in creating their own technology from often times destitute laboratories, 4) how the brain had to be defined before it could be understood and treated clinically, and 5) how a simple idea and ingenuity with the proper experimentation could address a neuroanatomical problem from animals to humans. This historic context has been an effective teaching approach during lecture with open discussions in class. The feedback from our undergraduate students has been overwhelmingly positive, in that student’s report they retain more about neuroanatomy with the historical examples linked to the structure-function relationships, rather than the structure-function relationships alone. The “story” context appears to engage their attention; they are more receptive and retain more information when teaching through this historical context. Historical vignettes are powerful modifiers of undergraduate student learning. When led through neuroanatomy’s rich evolutionary history, undergraduate neuroscience students appreciate current “hot topics” and technological advancements even more as evidenced by their active engagement in class discussions, their attitudes on the topics, and their grades in the course. Additionally, this approach also conserves ever-shrinking resources and avoids the ethical and psychological challenges of traditional approaches to the pedagogy of neuroanatomy.

Teaching neuroanatomy through a historical context would require the neuroscience educator to select major pioneers of the field and link their contributions to the field with how their work is relevant today (i.e., Nobel laureate's Santiago Ramón y Cajal's and Camillo Golgi's establishment of the neuron doctrine led to the discovery of the synapse and the broad range of brain imaging techniques used today to diagnose neuropathology). These rich historical examples can be used to highlight the importance of being able to see beyond the gross anatomy of the brain's sulci and gyri to understand how it functions. Once the neuron was visualized under the microscope, the many types of brain cells and their connections between neurons in a local area were then used by Korbinian Brodman to define boundaries to map the cerebral cortex (Loukas et al., 2011). This pedagogical approach in teaching neuroscience through a historical context has also been recently highlighted in educating the public through *The Beautiful Brain: The Drawings of Santiago Ramón y Cajal exhibit* (Newman et al., 2017). Arguably, these historical pedagogical approaches provide students with a deeper understanding of neuroanatomy, with a finer appreciation to the many great minds within the field of neuroscience, with a dual goal of educating them on neuroanatomy and inspiring them to consider a career in the neurosciences to perhaps one day offer their own contribution to the field. In order to keep our rich history of neuroscience thriving, we will need to stand on the shoulders of the field's giants to learn from its rich history in order to further advance the field for the next generation of neuroscientists. If we don't consider the history of the giants in the field of neuroscience within our teaching, we may be offering curricula to undergraduate students with all the giants gone (Harrington, 2015).

In summary, we encourage our colleagues to consider using this historical pedagogical approach in their neuroscience curricula, since it has shown to be effective. Tethering neuroanatomy curriculum to historical vignettes, will further aid undergraduate neuroscience students in re-contextualizing the great contributions from the past, which may be refuted, reworked, or recorded in the advancement of the field. Further, this historical pedagogical approach may perhaps address teaching neuroanatomy to an increasingly ethnically diverse population of undergraduate students by centralizing the neuroanatomy curriculum through historical contexts as a means to compensate for the range of pre-requisite issues when taking such a demanding course.

We argue that the narrative form is inherently integrative and is a powerful pedagogical tool when used in the teaching of complex, integrative concepts. It is an alternative approach to the more traditional one which results in a shallower understanding by students who use only procedural memory, and have lowered integrative ability and/or motivation towards integration in a field that increasingly requires greater integration across disciplines. It is also preferred by students with different learning styles preferences, and ethical concerns. The ethnic composition as well as the professional pathways of undergraduates is changing quite rapidly. If these various diversities are left unaddressed, it may become a serious problem in the training of future generations of neuroscientists.

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