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Review Article

Understanding the Autonomic Nervous System: A How-To Guide for Designing Engaging Pathophysiology and Pharmacology Courses for Nursing Students

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Aim. The objective of this article is to describe our innovative competency-based approach to teaching nursing students about the autonomic nervous system (ANS). *Background*. Nurse educators require resources about pedagogical approaches related to ANS instruction. *Design and Methods*. We implemented an approach based on Kolb's Experiential Learning Theory, which was piloted in several nursing courses that spanned undergraduate and graduate levels of education. *Results*. We organized content according to three core ANS concepts: receptors and ligands; neurotransmission; and ANS divisions and reflexes. After students demonstrated mastery of these concepts, we introduced active-learning exercises, such as case studies, interactive games, concept mapping, and simulation-based education. This approach layered clinically-relevant information upon the core concepts. We leveraged student feedback by adding historical, social science, and literary examples into lectures because students reported how this approach made the material engaging. *Conclusion*. Our approach guides students toward a conceptual understanding of the ANS to support critical thinking and enhance nursing skills, such as interpreting physiologic signals, titrating vasoactive medications, and recognizing ANS disorders.

1. Introduction

Success in nursing education depends on students' abilities to integrate fundamental knowledge about the autonomic nervous system (ANS) from a sequence of courses: anatomy, physiology, pathophysiology, pharmacology, and clinical rotations. The ANS controls involuntary physiologic functions, such as blood pressure, heart rate, breathing patterns, and digestion [1]. Conventionally, educators have relied on lectures (defined as oral presentations given online or face-to-face) to provide students with ANS information. An overreliance on lecturing, however, may hinder students' abilities to understand information conceptually and apply ANS knowledge to clinical decision-making [2, 3]. The American Association of Colleges of Nursing (AACN) has called upon educators to integrate innovative competency-based teaching methods into nursing curricula [4], and many technologies are evolving that could enhance student learning with animated visualizations of physiologic processes. Herein, we present an innovative and multimodal approach that addresses the challenges associated with teaching ANS concepts in nursing programs. Our approach situates ANS instruction within an experiential learning theoretical framework while incorporating many activities that increase student engagement.

2. Design and Methods

Our team designed curricula about physiology, pathophysiology, and pharmacology, which we delivered across four different courses required during the first year of the undergraduate or graduate nursing programs. These courses span many levels: a 200-level pathophysiology/pharmacology course for traditional Bachelor of Nursing Science (BSN) students, a 400-level pharmacology course for accelerated (graduate-entry) BSN students, a 500-level physiology course for Doctor of Nursing Practice (DNP) students, and a 500-level pharmacology course for DNP students. The approaches described in the present paper were utilized during the 2022-2023 academic year, when our courses enrolled 306 and 251 BSN and DNP students, respectively. The mean ages of students were 22 years (range 19–39 years) for traditional BSN students, 27 years (range 22– 39 years) for accelerated BSN students, and 31 years for DNP students (range 22–62 years). In addition to diversity in terms of age and different levels of education upon entry, the student cohort was diverse in ethnicity and race. According to student-reported data, 21% of students identified as Hispanic, 12% were Black, and 25% were Asian.

Each course lasts 16 weeks; instead of exclusively focusing on the ANS as one weekly topic, we introduced ANS concepts during the first week, and then the concepts remained a theme throughout the duration of each course. In our program, the BSN students attended ~4 hours of lectures weekly, live in the classroom, and the faculty provided opportunities for virtual office hours and an online discussion forum for out-of-class support. The DNP courses were taught asynchronously online (hosted by the university's learning management system). This asynchronous education opportunity was important because our college has campuses in different locations, and students could attend the online courses from any location. The DNP students watched prerecorded/captioned videos of lectures online (with ~1 hour of lecture time required per week). To support engagement, DNP students could also attend virtual faculty office hours and use an online discussion forum. Across these courses, exam scores were the primary evaluation tool to assess students' knowledge. For example, the DNP students completed four 50-item multiple choice exams to determine their grade, but they were incentivized to participate and receive extra credit points by engaging in the learning activities described in the present paper (e.g., up to 8% added to the final grade for engaging in case study discussions). A similar grading approach was used for the BSN students (e.g., points were earned from adaptive quizzes).

2.1. Theoretical Framework. We used Kolb's Experiential Learning Theory as our guiding framework. The stages in Kolb's [5] learning cycle include (1) concrete experience (engaging in a learning activity), (2) reflective observation (reflecting on the experience), (3) abstract conceptualization (learning from the experience and gaining knowledge), and (4) active experimentation (testing/trying what was learned). Within the context of acquiring ANS knowledge, Kolb's Experiential Learning Theory emphasizes the need for active-learning experiences that encourage students to transform, assimilate, and accommodate their experiences into new knowledge [5, 6]. Kolb's recommendations have been emphasized by the AACN's Essentials, which support competency-based education and active-learning approaches [4]. We used qualitative feedback from past students' course evaluations to inform our implementation strategies for competency-based education for BSN and DNP students and to determine which approaches increase engagement.

3. Essential Didactic Content (Core Concepts)

Well-organized didactic content is essential for providing students with the fundamental ANS concepts, consistent with the "concrete experience" described by Kolb [5]. Students also benefit from receiving content with visual, written, and oral formats along with a concise list of learning objectives. Our team of educators agreed that covering basic cellular and molecular processes was a crucial first step because students would build upon this information in their future lessons and clinical practice. For example, we described homeostatic mechanisms (e.g., heart rate regulation, glucose utilization, and baroreflex activation) before addressing clinical cases that involve perturbations (e.g., dysrhythmias, hypoglycemia, hypertension, syncope, and shock). When students reported struggling with content about disease states or therapies (e.g., drug mechanisms of action), we stepped back to review and deconstruct the basic physiologic concepts and neuroanatomy. We identified three core ANS conceptual areas students had to grasp before engaging with more complex topics: receptors and ligands, neurotransmission, and ANS divisions and reflexes (Table 1 lists additional examples and instructional approaches relevant to these core concepts).

3.1. Receptors and Ligands. Comprehensive knowledge about receptors and ligands was a prerequisite for understanding ANS functions. Our lectures provided students with a logical process for categorizing biological responses as well as the mechanisms of action of medications. For example, we emphasized that ANS receptors fall into two major categories (i.e., ionotropic and metabotropic) and that there are multiple subtypes within a given classification (e.g., five types of muscarinic receptors). We asked students to distinguish among receptor types based on their cellular locations (e.g., membrane-bound receptors (typically activated by water-soluble peptide molecules, such as insulin) versus nuclear receptors (activated by lipophilic hydrophobic molecules, such as steroid hormones)). First, we focused on the cholinergic and adrenergic receptor families and their roles in regulating basic physiologic processes, including cardiovascular functions, sleep and wakefulness, sexual functioning, urination, and digestion. By focusing on receptor types first, and their distributions throughout the body, students were prepared to anticipate why different drugs produced certain effects. Similar to McCorry [1], we believed that this approach was preferable to any attempts to memorize drug classifications without comprehensive molecular-level knowledge. Our lectures

Table 1: Examples of ANS fundamental concepts, topics, and learning activities.

Didactic content		Activities based on Kolb's Experiential Learning Stages			
Fundamental concept	Topic example	Concrete experience	Reflective observation	Abstract conceptualization	Active experimentation
Receptors and ligands	G protein-coupled receptors (excitatory and inhibitory)	Instructor shows students histology representing different types of neural tissue and discusses staining/detection methodologies for characterizing neurons	Students illustrate signaling cascades, including the effects on proteins, second messengers, and intracellular targets postlecture	Class develops charts with examples of drugs, the drug classifications, and mechanisms of action. Adaptive quiz modules are also available for self-paced study	Students administer different drugs intravenously during SBE and predict and respond to the associated changes (e.g., aminophylline epinephrine, dexmedetomidine, metoprolol, and phentolamine)
Neuro-transmission	Central versus peripheral tissues	Students create a list defining key cell types before class (e.g., glial cells and Schwann cells) and drugs that affect functions	Students submit brief written reports in preparation for case studies discussion about patients with multiple sclerosis, myasthenia gravis, Bell's palsy, or Guillain–Barré syndrome (focusing on symptoms and therapeutics)	Class compares patch-clamp recordings from different types of neurons and discusses the ionic currents Class examines a research article about acupuncture and discusses how reduced sympathetic simulation, endorphin release, and reduced catecholamine production would affect patients [7]	Students care for patients with ANS disorders during clinical rotations, ensuring to integrate observations about sensory, motor, cardiovascular, and respiratory assessments with the concepts taught during class
ANS divisions and reflexes	Arterial baroreflex and blood pressure regulation	Instructor provides a lecture about negative feedback systems	Students complete practice questions based on equations: cardiac output = heart rate • stroke volume	Instructor shows/explains recordings of arterial pressure, pulse, afferent baroreceptor nerve discharge, and efferent sympathetic nerve activity during class	Students engage in a simulation-based education experience and a reflective debriefing session about hemodynamic monitoring, intravenous fluid administration, and vasoactive drug titration
	Cardiac modulation (electrical conduction and heart rate variability)	Instructor discusses the sympathetic and vagal influences on the heart and the conduction system	Small groups, with instructor guidance, interpret the meaning of various metrics (e.g., mean and standard deviation of N to N intervals) [8]	Students complete a concept map or illustration showing the ANS innervation of the heart and action potentials characteristics in atria versus ventricles for instructor feedback	Students monitor fetal heart rate strips from SBE about a laboring pregnant patient and discuss clinical decision-making

included animations created by our team of educators to illustrate various ligand/receptor interactions and signaling cascades.

3.2. Neurotransmission. Neuron anatomy, nerve signal propagation (action potentials and graded potentials), neurotransmitter release, and muscle contraction were foundational concepts for understanding neural communication. Before studying ANS functions, we asked students to illustrate the components of a neuron (e.g., soma, synapse, axons, and dendrites) as well as gap junctions and membrane-bound proteins/receptors. The students also graphically depicted the phases of action and graded potentials (e.g., polarization, depolarization, hyperpolarization, and repolarization). Students were encouraged to share their illustrations with their classmates during their classes, virtual office hour meetings, virtual review sessions, or in the online discussion forums.

We also determined that fundamental knowledge required knowing the relative intracellular versus extracellular concentrations of ions (e.g., sodium, potassium, chloride, and calcium) and their corresponding ion channels along with the associated changes in the cell membrane potential. After teaching this information, we focused on the release and effects of neurotransmitters (e.g., acetylcholine) and their corresponding reuptake transport proteins and enzymes (e.g., the norepinephrine transporter for reuptake of norepinephrine and acetylcholinesterase for the degradation of acetylcholine into choline and acetate, respectively) [1]. We discussed how the ANS regulates cardiac, skeletal, and smooth muscle cell contraction after students studied the basic neuroanatomical and electrophysiological information. Similar to the neuron and electrical potential drawings, students shared their written descriptions of this topic by answering open-ended review questions and case studies with faculty and classmates during class or during office hours (BSN) or by posting their responses in an online discussion forum (DNP).

After mastery of the fundamentals, we asked students to examine more complex clinically relevant and pharmacotherapeutic concepts, which represented the "reflective observation" stage of Kolb's theory [5]. We discussed physiologic and pathophysiologic conditions within the context of recordings illustrating electrical activity in the central nervous system. For example, Figure 1 is used in a lesson for the DNP students to illustrate the activity of cortical neurons (electroencephalogram) in the brain during wakefulness and sleep [9]. Students shared information about many additional clinically relevant topics during our course discussions, such as circadian rhythm and sleep disorders (e.g., shift-work sleep disorder, narcolepsy, and sleep apnea) and the effects of hypnotic and stimulant drugs. We also provided exposure to relevant faculty research activities; for example, one faculty member (JMS) is a nurse scientist and a licensed acupuncturist, and her team's research illustrated how acupuncture can be used to manage pain and cardiovascular disorders, according to its effects on the ANS [10–12]. Other faculty members with active

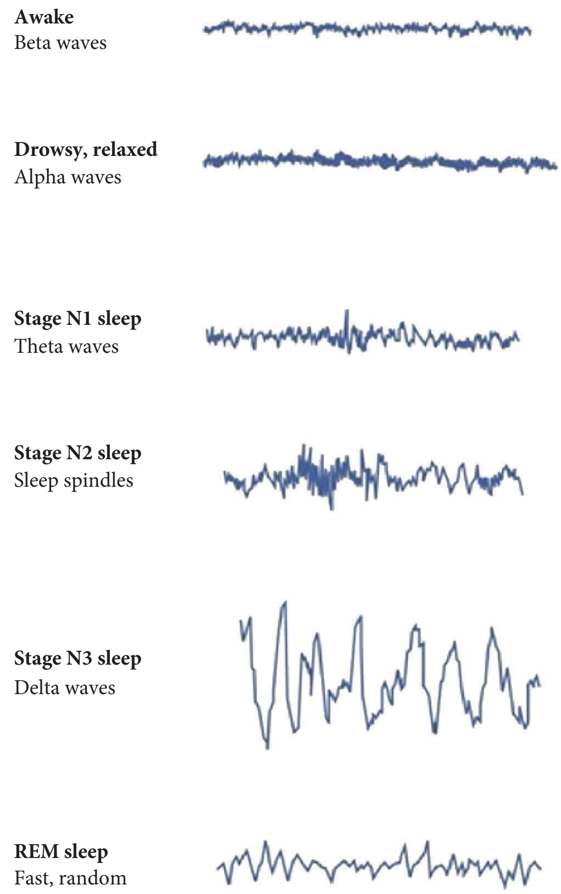

Figure 1: Cortical electroencephalogram signals during wakefulness and sleep [9]. This publication is licensed under the Creative Commons Attribution 2.0.

research programs incorporated examples from their relevant work about neuroscience (MWC and AMF; [13, 14]), stroke (SRM; [15]), diabetes (CF and LQ; [16]), and the microbiome (MBL; [17]).

3.3. ANS Divisions and Reflexes. Once students demonstrated an understanding of the fundamental molecular- and cellular-level mechanisms, we transitioned to a systems-level discussion to examine the central control of blood pressure, pulse, and breathing. Similar to Heesch [18], we determined that an important point to emphasize was how the sympathetic division of the ANS rapidly increases arterial pressure by constricting the arterioles, raising stroke volume, and increasing heart rate; the parasympathetic division's main effect evokes a reduction in heart rate. In addition, we recognized that McCorry [1] advised educators to include a discussion about the catecholamines produced by the adrenal glands (e.g., epinephrine) and to address the role of renin (secreted by the juxtaglomerular cells in the kidneys) in blood pressure regulation. In the asynchronous online DNP course, we also provided instructions for a hands-on experiment with water-filled balloons to illustrate the concepts of cardiac preload, afterload, and contractility.

The arterial baroreflex and peripheral chemoreflex were additional fundamental concepts within this category. We explained to students how baroreceptors (in the carotid sinus and the aortic arch) sense blood pressure changes (according to the stretch induced within the vessels) and chemoreceptors (in the aortic arch and carotid bodies) detect arterial blood chemical changes and project signals to the medulla to adjust breathing [18, 19]. We engaged students in discussions about these reflexive feedback systems, which illustrated Kolb's "abstract conceptualization" stage [5]. We also discussed the brainstem structures that have ANS regulatory roles (e.g., the Bötzinger complex for breathing) as described by Andresen et al. [20], Crisafulli et al. [21], and Fink et al. [14].

4. Our Approaches for Enhancing Student Engagement

According to Kolb's Experiential Learning Theory, nursing students will be motivated by knowing how their course content will apply in the workplace, and they need to engage in activities to experiment and apply what they have learned ("active experimentation"). To achieve this, we used the following tools: case study discussions, concept mapping, learning games, simulation-based education (SBE), and adaptive quizzing. Medications and types of ANS disorders provided us with numerous examples of interesting topics our students chose to explore during these active-learning exercises (Table 1).

4.1. Case Studies, Concept Mapping, and Games. We wrote numerous original case studies to illustrate clinical concepts for BSN and DNP students. According to the qualitative student evaluation feedback, the case studies helped students to recognize the clinical relevance of ANS information, especially when the case studies were comprehensive (e.g., included laboratory data, electrocardiogram strips, and patients' history and symptoms). We also included an optional assignment for DNP students to create their own concept maps, defined as diagrams that illustrate information and the relationships among physiologic systems (e.g., each of our core concepts within the context of an ANS disorder). Similar to recommendations from Stranford et al. [22] and Torre et al. [23], we asked DNP students to create and share a concept map about the ANS, pathogens and infections, and the immune system for extra credit. The purpose of this concept mapping assignment was to assist students in visualizing the "big picture" by linking content from their anatomy, physiology, biochemistry, and pharmacology coursework. Consistent with Kolb's Experiential Learning Theory, we also expected that case studies and concept mapping would support students with different learning-style preferences because visual, auditory, kinesthetic, and reading/writing approaches to learning were incorporated into the design/presentation of these assignments [5]. In addition, we created and incorporated many original learning games into our courses (e.g., word searches, crossword puzzles, matching exercises, and activities in an interactive gaming platform), which were designed to help students learn physiologic terminology.

4.2. Simulation-Based Education and Virtual Reality Simulation. Our college's Experiential Learning and Simulation Laboratory (directed by KJV) allows faculty to use SBE for active learning; this laboratory provides faculty with access to multiple simulation modalities with varying degrees of fidelity. For the present paper, only the BSN students performed SBE related to the ANS. The SBE could realistically reproduce clinical scenarios while aiding students and faculty in determining performance gaps. Educators conducted prebriefing sessions prior to SBE to explain well-defined learning objectives with the goal of understanding the learners' frame of mind. In addition, SBE was always followed by a debriefing session where learners reflected and received constructive two-way feedback, leading to new knowledge, personal growth, and confidence [24].

In addition, virtual reality (VR) simulation is a novel SBE modality that accelerates learning through the use of a headset with customized software, providing digital imaging to meet learning objectives. To date, our BSN students have trialed a VR platform from Oxford Medical Simulation, which gives students the opportunity to visualize 3D vasculature through a headset for studying pathophysiology instead of relying on textbook illustrations or plastic models. Our students and faculty are eager to continue working with VR because it is interactive and engaging and provides immediate feedback when identifying the strengths and weaknesses of learners [25].

4.3. Adaptive Quizzing. Two educators on our team (CF and MWC) found adaptive quizzing useful for BSN students—quiz results were due before the lectures, and the quizzes were "open-book" to guide students in familiarizing themselves with the terminology and topics that would be presented in the upcoming lectures. Adaptive quizzing also allowed students to evaluate their own knowledge as determined by their self-paced computer-administered tests. Adaptive quizzing programs determined students' quiz content according to their individual mastery levels—as students began answering more difficult questions correctly, the program provided them with more challenging questions [26, 27].

According to Pence and Wood [28], the main benefit of adaptive quizzing comes from allowing students to engage in self-directed remediation at their preferred rate of learning. In a study about nursing students who were studying pharmacology and pathophysiology, Austin et al. [29] found significant correlations between students' adaptive quiz mastery levels and their future standardized test scores. Our team has recently begun incorporating adaptive quizzing into our program to enhance students' knowledge about ANS topics and to acquire data about the correlations between quiz results and future learning outcomes.

4.4. Enhancing Student Engagement by Adding Historical and Literary References to Lectures. Qualitative feedback about our courses illustrated how many students desired information that reached beyond the sciences to make the ANS content engaging. Importantly, our graduate-entry program recruits "second degree" applicants—students who had degrees in other fields often requested examples that provided a broader context. For this reason, we began adding many of the historical and literary examples described below into our presentations.

We explained how research about the ANS has a long history in the fields of nursing, medicine, and pharmacology. Multilingual students were interested to learn how their language skills were relevant to understanding ANS terminology because early scholars wrote about ANS topics using many languages of classical antiquity (e.g., Arabic, Chinese, Greek, and Latin) [30]. Ancient Greek scholars—Hippocrates (circa 460–370 BC), Galen (circa 129–216 AD), and Aristotle (384–322 BC)—studied the ANS by investigating processes such as blood flow, breathing, sleep, and digestion [31]. The theory of the humours guided practitioners in ancient Greece, and later, throughout Europe—the humours referred to four categories of bodily fluids: blood, yellow bile, black bile, and phlegm. Human physiology was thought to be affected by the quantities of each humour [32], a topic our students found interesting because it linked medicine, science, history, philosophy, and literature. Crude and ineffective therapies, such as bloodletting, were commonly employed by practitioners who relied on the Theory of the Humours [32]. The popular Elizabethan-era playwright, Shakespeare (circa 1564–1616) referred to these humours to provide physiologic and psychologic descriptions of his characters. We used illustrations depicting Shakespeare's humours in a "Fluid and Electrolytes" lecture for BSN students who may have recently studied European literature in their prerequisite literary and history courses. For example, Falstaff's corruption was caused by too much blood (a sanguine temperament), and Ophelia's suicide was attributed to an excess of water, black bile, and phlegm (a phlegmatic temperament). Hamlet referred to the king's doctor's practice of catheterization to remove urine (yellow bile) to treat an angry temperament, and The Taming of Shrew's Petruchio told Katherina not to eat meat (a choleric food) in his attempts to turn her into a more agreeable bride. Macbeth's choleric temperament (a yellow bile excess) made him ambitious, but his murders altered his composition, leading to his madness and death (melancholic). In our lectures, we explained that although these plays represented mostly fictional events and characters, these works illustrated Western beliefs about the effects of bodily fluids on humans' health and involuntary activities [33–38].

The educator on our team who has expertise with acupuncture and the ANS (JMS) briefly discussed the influences of ancient medical perspectives across East Asia that focused on the importance of achieving an optimal harmony among human and environmental factors. By mentioning Western and Eastern perspectives in our classes, our team demonstrated respect for our students' diverse backgrounds. Ancient Chinese medicine was guided by the Theory of Yin and Yang, as described in The Yellow Emperor's Canon of Internal Medicine (codified during the Han Dynasty, 206 BC–220 AD). Yin and Yang are vital energies (called qi (pronounced "chee")) found within and around the body, and diseases were attributed to an imbalance of Yin and Yang [39, 40]. Balance was also an important ANS concept in Ayurvedic medicine, the ancient Indian healing system codified in the Vedas (2nd century BC). Ayurvedic healers worked to achieve a balance among the body's three doshas (vata (wind), pitta (bile), and kapha (phlegm)) and the five elements of the universe (air, water, ether, earth, and fire) [39]. Within both the Chinese and Ayurvedic medical systems, imbalances that cause disease have been treated with herbal medicines and dietary modifications. A practitioner using the Chinese medical system, for example, may have monitored ANS-related outcomes during acupuncture (e.g., heart rate) to observe the patient for signs of improvement [40].

Students were also intrigued by discussing how the Middle Ages and Renaissance were marked by growing knowledge about neuroanatomy and the circulatory system. For example, a Persian physician, Ibn Sina (also known as Avicenna, 980–1037), published extensive information about blood vessels and nerves in his Canon of Medicine, which influenced global views on the ANS for centuries [41, 42]. Our students appreciated seeing how artistic expressions became intertwined with science, as demonstrated by the highly accurate medical illustrations depicting the brain, vasculature, and muscles drawn by da Vinci (1452–1519) and Michelangelo (1475–1564). When De Motu Cordis was published in 17th century England, Harvey (1578–1657) was the first physician to correctly suggest that the left ventricle ejected blood into the systemic circulation and that the pulmonary artery received blood from the right ventricle [43]. We also discussed the discoveries of physiologists who investigated the circulation—Poiseuille (1797–1869), Frank (1865–1944), and Starling (1866–1927). These scientists devised equations to quantify and predict relationships among variables reflecting blood flow, viscosity, pressure, or volume [44, 45]. For the DNP students, for example, we provided a brief lecture about the discoveries, and then students had a series of exercises about intravenous fluid administration to illustrate the variables in the equations published by these scientists (e.g., Poiseuille's law to describe fluctuations in flow according to pressure and lumen radius changes).

5. Conclusion

In summary, the ANS is a priority topic for educators who are integrating neuroanatomy, neurophysiology, pathophysiology, and pharmacology content into nursing courses. We used Kolb's Experiential Learning Theory as a framework for developing ANS-related educational activities; this theory is useful because it emphasizes the practical application of ANS knowledge and encourages active learning. We structured our content around three core conceptual areas: receptors and their ligands; neurotransmission; and ANS divisions and reflexes.

Our conceptually based approach to learning about the ANS will prepare competent students for success with their future clinical responsibilities, such as evaluating diagnostic information, analyzing physiologic signals, and administering medications. Students also reported how their engagement with our presentations was enhanced when the aforementioned historical, social science, and literary examples were included in lectures to broaden the context of the ANS information.

Importantly, a limitation of our paper involves the lack of quantitative data about students' exam scores, graduation rates, and future licensure pass rates. We did not have a control group of students (i.e., students who did not receive our teaching approach), and therefore we did not statistically compare outcomes associated with different teaching approaches. For the present paper, this type of quantitative analysis and controlled study design was not feasible, and many confounding variables would correlate with outcomes (e.g., differences in baseline ANS knowledge across classes, which we did not measure). In the future, however, we will design pretest/posttest studies to determine how different teaching approaches correlate with objective evidence of students' long-term professional success while controlling for confounding variables, such as prior knowledge about the ANS.

Data Availability

No data were used as this is a review paper.

Disclosure

The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH. The final peer-reviewed manuscript is subject to the NIH Public Access Policy.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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