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Undergraduate neuroscience education: Meeting the challenges of the 21st century

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ABSTRACT

The dedication of undergraduate neuroscience faculty to their students could not have been more evident than what these educators demonstrated when the COVID-19 pandemic impacted colleges and universities across the United States. These faculty faced the crisis head-on to provide their students with exceptional instruction in virtual formats that many faculty had never used for instruction before the pandemic. This same tenacious attitude has been reflected in pedagogical efforts that undergraduate neuroscience faculty have undertaken since the mid-1990s. The challenges of providing cutting-edge neuroscience education to undergraduates in a dynamic field have produced a series of curricular designs and approaches that capitalize on discipline-based education research. This article reviews curricular models and pedagogical strategies aimed at enhancing the educational experiences of undergraduate neuroscience students whose lived experiences and academic backgrounds reflect the richly kaleidoscopic demographics of college students in the 21st century. The future of undergraduate neuroscience education is bright as faculty and their students collaborate on their journey of discovery in neuroscience.

1. Introduction

"Adversity is not without comforts and hopes."
Sir Francis Bacon

As 2020 dawned, many educators in the neuroscience community in the United States were preparing for their spring semester classes. Marvelous college courses in fields as diverse as molecular neuroscience and clinical neuropsychology were crafted and tuned by dedicated faculty from small liberal arts colleges to large research universities. These neuroscience faculty were assembling the supplies and the equipment that they and their students would be relying on in their explorations of the nervous system in a wide range of *in vitro* and *in vivo* preparations. The emergence of SARS-CoV-2 in late 2019, however, soon upended the discovery journeys many neuroscience faculty and students had embarked on at the beginning of the semester. Because of the COVID-19 pandemic resulting from SARS-CoV-2 transmission, by March 13 some 300 American colleges and universities had moved their classes online [1]. Subsequently, hundreds more converted to some form of remote learning – aka distance and online learning – severely restricting access to campus that eliminated hands-on, laboratory experiences for many science students [2]. This crisis in education was unique and cut across all sectors of the academy, but was especially traumatic in fields based on bench work and personal instruction such as that used in the neurosciences. Nothing like it had ever been seen by faculty who have been teaching for over 50 years through recessions, the wars in Vietnam, the Persian Gulf, and Afghanistan, or upheavals on college campuses during the 1960s. At the time of this writing, the future of higher education remains uncertain.

In Sir Francis Bacon's essay "Of Adversity" [3] we are reminded that hope may be found even when challenges arise. Based on how the undergraduate neuroscience education community responded to the COVID-19 crisis, I am hopeful indeed! The reality of having to immediately convert a course from an in-person experience in a campus classroom or lab to a remote learning environment in the matter of days traumatized many faculty. Especially traumatized were the students who were accustomed to in-person education and were now with just a few days' notice being required to leave their dorm rooms, friends, and campus life. Within the neuroscience education community from around the world, there was a tremendous outpouring of mutual support on the Faculty for Undergraduate Neuroscience (FUN) listserv. Neuroscience faculty shared numerous resources for remote learning – beginning with posts from William Grisham at the University of California at Los Angeles and Ashley Juavinett at the University of California at San Diego on March 11, just days after Stanford University and Touro College

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became the first institutions to announce their transitions to online instruction on March 6 [2]. Following Grisham's and Juavinett's posts numerous faculty members and the Neuroscience Scholars Program at the Society for Neuroscience shared resources to facilitate the conversion of in-person teaching to a digital environment. By March 18 Annaliese Beery and Richard Olivo at Smith College and Robert Calin-Jageman at Dominican University had assembled compilations of all the resources shared by the FUN community for broad distribution among neuroscience education community members. Because of the COVID-19 pandemic, by midsummer the in-person FUN workshop that had been planned for July at Davidson College as a celebration for the 25th anniversary of the inaugural FUN Workshop at Davidson (see discussion below) was quickly converted into a virtual workshop. Alo Basu at the College of the Holy Cross and Jason Chan at Marian University spearheaded this effort (with support from the organizing committee) that focused on best-practices in distance learning and inclusive pedagogy. The shared goal of all these tremendous efforts was to continue providing undergraduate neuroscience students, *all students*, with innovative educational experiences that would, even under these difficult circumstances, reveal the extraordinary beauty of the nervous system – the very organ in human beings that will ultimately be responsible for fashioning the cures of this global pandemic. In the remainder of this review, I will explore how the undergraduate neuroscience education community has addressed pedagogical challenges by creating opportunities to innovate in undergraduate neuroscience learning spaces.

2. Developing neuroscience curricula

Although the Society for Neuroscience (SfN) was founded in 1969 and courses in neurobiology and physiological psychology had been taught for years before then, it was not until 1995 that the first national effort to craft blueprints of undergraduate neuroscience curricula was launched at a workshop titled "Interdisciplinary Connections: Undergraduate Neuroscience Education" sponsored by FUN and Project Kaleidoscope that Jeanne Narum (Executive Director of Project Kaleidoscope) and I organized at Davidson College in North Carolina (see Fig. 1 for the Workshop Leaders). This FUN Workshop marked an important innovation relative to previous Project Kaleidoscope meetings since we targeted curricular development and included innovative, hands-on, laboratory exercises as part of the workshop that Carol Ann Paul and Bruce Johnson organized. Since then FUN has held meetings every three years through 2020 (including a virtual workshop in 2020) that have explored curricular innovations in classroom and laboratory instruction as well as issues of accessibility to neuroscience through dialogues on diversity and inclusion. Five sets of pedagogical and curricular recommendations [4–8] emerged from those meetings informed by broad conversations that engaged all the participants at the FUN Workshops leading up to these publications. The evolution of these curricula often echoed the recommendations made by concurrent efforts at the American Association for the Advancement of Science [9], the National Research Council [10–13], and the Howard Hughes Medical Institute [14]. Notably, curricular recommendations for undergraduate education from life science professional societies are relatively unusual and would be a welcome addition to support educational initiatives in undergraduate science education more broadly [15]. Ultimately, this investment in the neuroscience curriculum led to the establishment of the *Journal of Undergraduate Neuroscience Education*, FUN's flagship journal that Barbara Lom as Editor-in-Chief and I as Senior Editor founded in 2002 with the support of a dedicated Editorial Board, to create a forum for sharing curricular ideas as well as innovations in neuroscience education whether in the classroom, the laboratory, or other venues [16].

3. The neuroscience program landscape

The potential impact of these efforts to provide some coherence to undergraduate neuroscience education has become especially important given the explosion in the growth of neuroscience programs at the undergraduate level. In a series of reports, Ramos and colleagues [17–20] mined the database of the National Center for Education Statistics at the United States Department of Education. In their 2011 report, which was the first analysis of nationwide trends in the availability of undergraduate neuroscience majors, Ramos et al. [17] observed that the number of undergraduate institutions offering neuroscience majors increased from only seven institutions in 1986 to 90 schools in 2006. Subsequent analyses documented further evidence of this growth trend such that the

Fig. 1. Workshop leaders at the inaugural 1995 workshop on "Undergraduate Neuroscience Education" held at Davidson College and sponsored by FUN and Project Kaleidoscope. Front row from left to right: Bruce Johnson, Carol Ann Paul, Julio J. Ramirez (organizer), Gary L. Dunbar. Back row from left to right: Pamela E. Scott-Johnson, Dennison Smith, Leonard E. Jarrard, Lin Aanonsen.

number of institutions offering undergraduate neuroscience majors increased to 221 institutions by the 2017–2018 academic year [20]. Although the precise number of students majoring in neuroscience is somewhat difficult to pinpoint because of vagaries in how neuroscience programs are identified, these reports indicate that by 2017–2018, over 7000 students had graduated with majors in neuroscience. Indeed, among the life sciences, neuroscience was frequently the source of the greatest number of life science majors at many institutions. As to the nature of the institutions offering majors in neuroscience, based on an analysis of databases available at Cappex.com and Collegeboard.org, Pinard-Welyczko et al. [21] reported that the majority of programs appear to be in private institutions (76%) and small liberal arts colleges (62%; small defined as 6000 or fewer students). Interestingly, in a survey of a wide range of four-year colleges and universities, undergraduates at liberal arts colleges report valuing their neuroscience courses more than undergraduates at national universities [22]. Finally, paths leading to exposure to neuroscience may be greater than reported in the studies described above since the focus of these analyses were on majors *per se*; minors and concentrations may also be available at a range of schools that do not offer a major, but nonetheless provide foundational experiences in neuroscience [5,8]. Notably, 70% of institutions offering a neuroscience major do not offer minors [21], though it is not currently clear how many programs offer solely a minor.

4. Overarching objectives of a neuroscience education

Considering the curricular and pedagogical recommendations that have been published over the years emerging from FUN Workshops [4–8] as well as from federal agencies, scientific societies, and private foundations [9–14,23], several themes emerge as being particularly important for providing a sound education that will prepare neuroscience students to contribute substantively to the biomedical workforce and to participate in national discourse as informed citizens.

Indeed, the centrality of these notions for undergraduate neuroscience educators was captured in the most recent set of curricular recommendations from the 2017 FUN Workshop organized by Eric Wiertelak, Irina Calin-Jageman, and Robert Calin-Jageman at Dominican University [8], which have been modified and updated from the recommendations [5] that emerged from the Davidson College meeting in 1995. In addition, Kerchner et al. [7] in their survey of undergraduate neuroscience faculty following the 2011 FUN Workshop hosted by Karen Parfitt at Pomona College identified a set of core competencies that also are evident in these notions.

First, an undergraduate education in neuroscience should promote critical and integrative thinking. Foundational experiences across a neuroscience curriculum should cultivate skills such as identifying the most salient elements of a reasoned argument, developing the wherewithal to assess the adequacy of methodology deployed in experimentation, and determining whether assertions of linkages between outcomes, observations, and interpretations are rational. Because neuroscience as an interdisciplinary endeavor crosses multiple levels of analysis in elucidating the behavioral consequences of nervous system function, curricular efforts to promote integrative thinking is important, though perhaps less so than critical thinking as indicated in the Kerchner et al. [7] survey. Indeed, Mennerick [24] has argued that the most significant element of an undergraduate education to prepare students for graduate studies in neuroscience is the promotion of critical thinking skills.

A second key feature essential for a sound undergraduate education in neuroscience is the development of communication skills wherein students can clearly convey their thoughts in writing, orally, and visually. The unfortunate stereotype that communication skills are not as critical in the scientific enterprise as in other liberal arts domains may hinder student intellectual growth, unless neuroscience programs underscore the importance of communication among scientists. Ironically, as Akil et al. [25] point out, a casualty of enhanced scientific training at the undergraduate level may be proficiency in communication skills.

A third outcome of a sound undergraduate neuroscience education should be the ability to articulate the interdisciplinary and interdependent nature of the neuroscientific enterprise. Both the National Research Council [10] in *BIO2010* and the American Association for the Advancement of Science [9] in *Vision and Change* emphasized the importance of interdisciplinary education in the preparation of future research biologists, with which neuroscience organically aligns. Exposure to and deep dives into problems that range from molecular neuroscience to the emergence of consciousness in human beings naturally cross disciplinary boundaries and are part and parcel of neuroscience education. Indeed, even after exposure to a single course in neuroscience, an undergraduate student should demonstrate an understanding that within neuroscientific explorations of the nervous system disciplinary boundaries are better thought of as porous membranes rather than impermeable barriers.

As particularly emphasized in *BIO2010* [10], *Vision and Change* [9], Akil et al. [25], and Wiertelak et al. [8], a fourth objective for a sound education in neuroscience is to promote competency in quantitative reasoning skills. Just as in other arenas of the life sciences, in order to explore neuroscientific phenomena in sophisticated and informative ways, undergraduate students need to develop facility with creating quantitative representations of the phenomena under investigation, statistical methodologies to assess the meaningfulness of discoveries arrived at through experimentation, and data analytics involving computational and programming skills.

A fifth objective emphasizes competency in experimental design, such as crafting a scientific hypothesis and the experiment to properly test it – *Vision and Change* [9] refers to this as "the ability to apply the process of science." In their study of competencies most valued by undergraduate neuroscience faculty, Kerchner et al. [7] indicate that promoting skill development in experimental design is an essential component in undergraduate neuroscience education. Indeed, given the current crisis in rigor and reproducibility in the life sciences [26], providing a strong foundation in experimental design with additional training in the responsible conduct of research and ethics [25] is of paramount importance. This would ensure that scientific discovery would be untainted and that the next generation of neuroscientists is well positioned to avoid the pitfalls that have undermined the public's confidence in biomedical scientific research [27].

A sixth objective of a neuroscience education is to promote an appreciation for how the neuroscientific enterprise may contribute to the discovery of solutions to vexing problems confronting society – an objective echoed at the first FUN Workshop at Davidson College [5] and more recently in *Vision and Change* [9]. An undergraduate neuroscience education is particularly well positioned to help students understand the importance of biomedical discovery to human health and well-being. Certainly, it can help students articulate how discoveries in neuroscience are applicable to our understanding of nervous system structure and function. Importantly, a neuroscience education can also illustrate how that understanding may be applicable to curing currently intractable diseases such as Alzheimer's disease as well as to providing, for example, a scientific basis for public health interventions aimed at mitigating the negative consequences of brain and cognitive development resulting from poverty [28].

5. Essential structural elements for 21st century neuroscience education

As noted in *Vision and Change* [9], curricular efforts to provide a sound foundation in life science education should jettison attempts to offer sweeping, wide-ranging overviews of the sciences with superficial coverage, but should instead focus on fewer concepts and with more depth in a given course. Analogously, as developing neuroscience programs consider which courses will serve as the foundational experiences for their students, it is advisable to consider how current faculty may be best prepared to cover neuroscience subfields as well as future directions an institution may want to pursue by hiring faculty prepared to teach burgeoning neuroscience areas. Indeed, as early as the first FUN Workshop in which numerous courses were listed as potential sources for crafting neuroscience majors, minors, or concentrations within biology and psychology departments (the so-called Blueprints), the workshop participants were careful to point out that institutions should design programs that speak to their faculty's strengths [5,8]. Indeed, as *Vision and Change* [9] underscored, ultimately science education initiatives should focus on both the foundational knowledge defining a particular scientific field (core concepts) and the fundamental skills necessary to conduct scientific work (core competencies).

One particularly evident feature of the curricular models emerging from the FUN Workshops is the vertical structure of the curricula. Educational experiences at lower levels create the knowledge base and investigative skills upon which later educational advances are founded. The three-tiered approach introduces undergraduates to neuroscience through a series of stages (with a heavy emphasis on inquiry-based learning throughout): 1) An introductory level that highlights the history, language, methodologies, fundamental principles, and the big questions that neuroscientists address in the research enterprise, as well as how neuroscience informs the dialogue between science and society. 2) An intermediate level that immerses students into deeper explorations of the concepts, discoveries, methodologies, and principles of neuroscience. Students should be trained to read critically the primary literature (see Pugh-Bernard and Kenyon, [29] - this issue, and Bodnar et al., [30], for training strategies), to undertake library research using modern digital technology, and to develop skills for designing experiments, analyzing data, and preparing scientific reports for oral, visual, and written presentation (see Petersen et al., [31] - this issue, for teaching methods in writing as part of an undergraduate neuroscience curriculum). A goal of the intermediate level of education is to prepare students to launch their own original research in areas of particular interest to them as they approach their junior and senior years. 3) An advanced level that has as its goal the preparation of students to undertake original scientific investigation. When students achieve this advanced level of education, they should now be capable of demonstrating deep and critical knowledge in their fields of interest, sophisticated skills in designing, quantitatively analyzing, and interpreting the outcomes of original experiments, and excellent skills in communicating their findings orally, visually, and in writing. The demonstration of these skills might appear in senior theses as well as poster or platform presentations in classroom settings or local meetings at their home institutions. Students should be encouraged and financially supported to present at local, regional, or national conferences, such as at the Northeast Under/Graduate Research Organization for Neuroscience (NEURON; [32]), the Symposium for Young Neuroscientists and Professors of the SouthEast (SYNAPSE; [33]), and the FUN Undergraduate Poster Session at the annual meeting of the Society for Neuroscience. Based on the capacity of a given institution to support individualized student research, some neuroscience programs may be better positioned to provide alternative capstone experiences, e.g. a senior seminar, in which students may delve into theoretical arenas requiring deep knowledge of the primary literature, may hone their skills in critical and integrative thinking, and may develop their ability to communicate their scholarly insights effectively. Such capstone experiences may also provide the means by which students can be encouraged to demonstrate their knowledge of the interdisciplinary nature of neuroscience and the role that neuroscience may play in solving significant societal problems.

6. Advances in neuroscience pedagogy

Discoveries in discipline-based education research (DBER) over the last several decades have elucidated a number of excellent pedagogical strategies to enhance undergraduate education in science, technology, engineering, and mathematics (STEM). According to *Reaching Students* [13], this body of research has demonstrated that focusing educational efforts on the student experience rather than on the instructor's delivery of information in unidirectional lectures (i.e., the "sage on the stage" approach) can dramatically improve student enthusiasm for and performance in STEM courses. This is not to say that lecturing should be completely abandoned, as it can still be an effective way to disseminate knowledge [34]; indeed, Stains et al. [35] have demonstrated that in STEM courses the dominant educational approach in North America continues to be the lecture. Rather, DBER has demonstrated that lectures can be augmented or judiciously deployed to better engage students as active learners when the instructor takes into consideration the student experience, the student's preparedness to undertake a given path in science education, and how students learn [12]. Using recommendations from the National Research Council [10,13], the National Academies of Science, Engineering, and Medicine [23,36], and the American Association for the Advancement of Science [9] as our guide, we will review several strategies that have emerged from DBER in neuroscience and related areas to enhance undergraduate education.

6.1. Undergraduate research experiences

The importance of undergraduate research experiences in the preparation of the next generation of scientists was fully embraced by the Council on Undergraduate Research (www.cur.org) in the 1980s and upon FUN's (www.funfaculty.org) founding in the early 1990s. These two organizations recognized the importance of providing undergraduate students with the opportunity to conduct research as an essential experience in their education. Indeed, FUN held the first national undergraduate neuroscience poster session celebrating undergraduate research at the 1996 SfN meeting in Washington, D.C. – a tradition that continues to this day as evidenced by the robust participation of well over 100 undergraduate students at the FUN Undergraduate Poster session at the 2019 SfN annual meeting held in Chicago. The growing interest in launching regional undergraduate neuroscience meetings (such as NEURON and SYNAPSE discussed above) showcasing undergraduate research is indicative of the commitment faculty have to providing students with hands-on, original research opportunities. As the National Academies of Sciences, Engineering, and Medicine 2017 report [23] on *Undergraduate Research Experiences for STEM Students* indicates, a growing body of literature suggests that participation in undergraduate research is beneficial to students and may have enduring positive impact on their career choices, knowledge of experimental design, attitude towards science, and confidence as young researchers (e.g., [37]). The benefits of engaging in undergraduate research as part of a faculty-led research team conducting original scientific investigations may have particularly positive effects on motivation to pursue a science career and socialization for undergraduates from underrepresented groups in the sciences [38,39]. Interestingly, several reports [24,40,41] suggest that graduate school admissions teams in neuroscience-related programs highly value undergraduate research experience as part of the assessment for graduate school entrance.

Although the apprenticeship model in which students are immersed in original research in a principal investigator's laboratory during summer or during the academic year is common at many institutions [42], these apprenticeship experiences may not be available to many students such as those from groups historically underrepresented in the sciences, as well as first-generation college students. One approach to improve accessibility is to incorporate discovery-based research into undergraduate courses [36,43 - this issue]. In one early report [44], I touched on such a strategy deployed in an introductory behavioral neuroscience course at Davidson College with a typical course enrollment of 15 students to energize my students in neuroscience by immersing them in the discovery journey. Over a several year period beginning in the mid-1980s, students in the course investigated the role of the entorhinal cortex in the performance of a differential reinforcement of low-rate responding task as a pilot study. The undergraduate research team that followed up subsequently on the project and I published our findings [45]. Interestingly, these undergraduate co-authors were a diverse team of young researchers consisting of one male student with a motor disability, two women (one of whom was Latin American), and a Latin American male student. In a particularly innovative exploration of course-based research experiences, Nahmani [46] utilized *open-access* image volumes to immerse undergraduate students in analytical work focused on the construction of three-dimensional representations of synaptic spinules in presynaptic boutons from cortex and hippocampus. The undergraduates were able to test hypotheses they crafted as part of the course, to contribute to the research program of the course instructor, and to make potentially novel discoveries as part of their course experience. A particularly appealing feature of this approach is that the data are freely available, thus making the approach available to a wide range of institutions. A recent report by Rodenbusch et al. [47] underscores the importance of enhancing accessibility to the discovery process by incorporating novel research activity into courses. In their analysis of undergraduates who participated in a three-semester Freshman Research Initiative (FRI) program at the University of Texas at Austin, Rodenbusch et al. observed that the participating students persisted in obtaining a STEM degree and graduated within six years at higher rates than those students who did not participate in the FRI program. Importantly, FRI program students from historically underrepresented groups in the sciences were as successful as other students who participated in the FRI program in their persistence to the STEM degree and in graduation rates.

6.2. Active learning

An abundance of research has demonstrated that helping students to become agents in their own learning, such as by having them "select, organize, and integrate information" they are learning, can dramatically improve student enthusiasm for and performance in science courses as well as promote enhanced critical-thinking and problem-solving skills [13,48–50]. To exemplify this pedagogical approach, I will focus on several active learning techniques that have proven to be effective and several of which I have used in my own courses (for excellent reviews of active learning techniques see Lom [51], National Research Council [13], and Williams and O'Dowd ([52] - this issue).

6.2.1. Think-pair-share

Although not a new idea, as an example of cooperative learning Lyman's [53] technique has proven to be especially effective in promoting critical-thinking skills, attitudes towards peers and the instructor, and the subject matter covered in the class [13,54]. With this cooperative learning technique students are given a prompt to consider on their own for a few minutes, then are asked to discuss their ideas with another member of the class, and finally are requested to share their dyad's discussion with the whole class. This method may be a particularly useful strategy to encourage students who might otherwise be hesitant to speak up in class to engage in a one-to-one conversation with a peer to have their ideas examined in a relatively low-stress environment. One method instructors can use to practice inclusiveness in their teaching and to encourage accountability among their students is to select systematically members of each pair to report on their discussion throughout the class period so that every student has an opportunity to report out to the whole class.

6.2.2. Brief quizzes

Evidence from cognitive psychology has demonstrated that frequent low-stakes testing may significantly improve students' performance on subsequent tests of the previously learned material [55]. Applying any number of testing modalities (such as short-answer or multiple choice), an instructor uses testing not only to explore whether a student may have retained some previously learned information as an assessment tool, but also as a way to help a student rehearse the recently learned information to promote further learning – the so-called testing effect [56]. I frequently start a class by giving five multiple-choice questions drawn from material covered in the previous class and have the students share their responses anonymously in a "clicker" kind of response environment (I use the Socrative.com app (Showbie, Inc., Edmonton, Canada) available for free for up to 50 students). Another approach to consider is administering pre-class quizzes in which students are tested on material assigned in advance of a class meeting. As Williams and O'Dowd ([52] - this issue)] underscore, these assignments should be straightforward, short, and guided.

6.2.3. Peer instruction

In the early 1990s, Eric Mazur introduced an effective method to improve students' understanding and problem-solving skills in his undergraduate physics course [13,57]. The approach combines strengths of the "Think-Pair-Share" and the "Brief Quizzes" approaches described above. After an instructor gives a brief presentation on a given topic, the students are asked to answer with a clicker (or some similar approach) a ConcepTest (e.g., a multiple-choice question) that probes their conceptual understanding of the material just covered. Subsequently, the students discuss their answers with neighboring peers in an effort to convince one another of the correctness of their original answers. Finally, the instructor again polls the students for their answers and then addresses the outcome of the group assessment and the correct answer. Thus, the students have an opportunity to engage in cooperative learning with other students and to experience several low-stakes tests to aid in memory retention of the newly learned material.

6.2.4. Reader's theater

As Lom [51] discusses, Reader's Theater is a technique that is commonly used in primary and middle school [58] to encourage students to read out loud in class from prepared text (such as a short passage), which serves as a low-stress technique to encourage students to speak in class and to help promote their self-confidence. Depending on the nature of the text to be read aloud, students may have opportunities to exercise dramatic or humorous approaches in their reading. In my classes, I have used excerpts from scientific papers that emphasize discovery (often tracing the historical evolution of an idea over several papers discussed in class) and that we follow up with other active learning techniques, such as Think-Pair-Share, to explore more deeply the importance of the discoveries.

6.2.5. Team-based learning

Although described in the early 2000s [59], team-based learning (TBL) has only recently been examined as a method to enhance the educational experience of students in neuroscience classrooms [60,61]. TBL deploys elements that have proven to be effective in promoting learning such as frequent testing and peer-to-peer interaction, but the approach is based on a highly structured series of steps that make the students especially accountable to themselves and to their team members for their learning. As Pollack [60] describes, the steps begin with a "flipped-classroom" strategy in which the students are assigned material to learn before they attend the class. Upon arrival, students are given an individual Readiness Assurance Test (RAT) that explores their knowledge of the assigned readings as a closed-book test. Some instructors may prefer instead to start the class with a mini-lecture before administering the RAT [61]. The students subsequently assemble as members of their assigned teams (five to seven members per team) to take the same closed-book RAT but as a group discussion-based experience that receives immediate feedback on their answers. The team RAT is immediately followed with a mini-lecture addressing the most complex problems in the assigned reading as well as student questions. Subsequent class meetings focus on content application activities that require students to use in-depth knowledge and to think critically as they solve important problems. Assessments by Pollack [60] as well as Ng and Newpher [61] indicate positive outcomes in terms of exam performance, class attendance, or self-reports on student learning. Indeed, these improvements were evident over courses that were either taught with traditional lecture techniques [60] or moderate active-learning techniques [61]. Because teamwork is now understood to be foundational aspect of the scientific enterprise [62,63], immersing undergraduate neuroscience students in the collaborative spirit evidenced in team-based learning is especially appealing.

6.2.6. Combining approaches and remote learning

Notably, instructors may effectively combine some of these techniques to promote the intellectual development of their students, which I have frequently done in my own classes. For example, one might set the stage for discussion among students with the Reader's Theater or Brief Quizzes then follow up with the peer-learning approach as illustrated with Think-Pair-Share or Peer Instruction. Indeed, as teachers have discovered because of their on-the-fly educational experimentation during the COVID-19 pandemic, many of these approaches can also be deployed creatively in online environments for remote learning. For example, small-group discussion as reflected in Think-Pair-Share can be conducted in virtual breakout rooms and the small-group insights can be shared subsequently with the whole class. Collaborative work, echoing Peer Instruction, with digital texts can be conducted with web-based applications such as Hypothesis (web.hypothes.is) or Perusall (www.perusall.com), which will also provide students with an opportunity to build community, albeit a virtual one.

6.3. Inclusive pedagogy

Structural obstacles, unwelcoming institutional climates, systemic failures in education and the scientific enterprise driven by racial, ethnic, gender, and ableist biases have undermined the national effort to engage the full breadth of talent within America's borders. This talent is essential to solve the significant challenges of the 21st century such as the climate crisis or the health disparities that have become glaringly evident as the COVID-19 pandemic unfolded in the United States and disproportionately hospitalized or killed members of racial and ethnic minorities [64]. Decades of literature underscore these failings to fully engage members from historically underrepresented groups in STEM such as women, African Americans, Latin Americans, American Indians, Alaska Natives, and persons with disabilities [65–69].

Efforts to embrace the totality of America's talent are crucial to discover the solutions to the challenges confronting society. There are hopeful signs from DBER reports that students from historically underrepresented minority (URM) groups in STEM may benefit significantly from active learning approaches, a potential consequence of which would be to help these students flourish and persist in STEM fields. In a meta-analysis of 41 studies reporting on a total of 53,844 students, Theobald et al. [70] discovered that active learning approaches dramatically narrowed achievement gaps, as measured by examination scores and passing rates, between URM/low-income students and those overrepresented in STEM, such as Asian American or Caucasian students. Although they did not dissect the active learning approaches used in the studies they analyzed, in aggregate for active learning experiences their findings indicate a 33% reduction in achievement gaps in performance on examinations and a 45% reduction in the gap for the probability of passing STEM classes between underrepresented students and overrepresented students. They persuasively argue that because other methods that have been used to address these achievement gaps, such as supplementary instruction programs or summer-bridge experiences, are expensive and unsustainable at scale, efforts to incorporate active learning approaches across STEM curricula would be an efficient and large-scale method to address the inequities in STEM education. Inclusive education, however, would not be limited to the deployment of active learning strategies, but would also include the incorporation of "soft skills" on the part of the instructor such as treating students respectfully, communicating a belief that they are capable of meeting high expectations, and showing an investment in the student's growth [70]. Not coincidentally, these latter recommendations are key elements in being a successful and effective mentor of undergraduate STEM students [71].

Active learning is not, however, a panacea for mitigating the effects of bias in classroom or laboratory settings. Despite the promising outcomes of Theobald et al.'s [70] report, findings from two recent publications [72,73] in particular serve as important reminders that the use of active learning strategies must be done within an overtly inclusive framework of education. In the Aguillon et al. [72] report on active learning, men participated in class interactions at significantly greater rates than women after small-group discussions in an introductory biology class at a major research-intensive university, and the women reported experiencing lower-levels of scientific self-efficacy. In the Macke et al. [73] study of team-based learning, peer evaluation scores that were assigned to the Black student members of teams were significantly lower than the White students in the teams despite comparable grade point averages and course grades in a variety of social work classes at a Midwestern public university. Thus, gender and racial biases may negatively impact student experiences even in active learning environments. As both sets of researchers indicated in their publications, it is incumbent on instructors deploying active learning strategies in their courses to emphasize inclusiveness and equitability as they craft their course experiences.

7. Final reflections

As we contemplate the future trajectory of undergraduate neuroscience education, are there arenas in which we can focus our efforts to ensure that students are provided with the experiences in their neuroscience studies to help them delight in the marvelous discoveries of the future?

7.1. Faculty engagement

Clearly, faculty enthusiasm for teaching nascent neuroscientists is an essential element for effective teaching. Whether as a "guide on the side" or as a "sage on the stage," instructors should unabashedly display their passion for the material they teach and their authentic interest in their students as budding scholars. Experience with a teacher who truly cares about a student and what they learn can be a transformative experience in one's life. I imagine that many who are now reading this text may recall the teacher whose belief in their students' abilities and love of their subject matter ignited a passion for learning that is palpable even years after one's graduation from elementary school, high school, or college.

A teacher's fundamental belief in a student's capacity to learn has recently been shown to have an impact on the academic performance of students, especially students who are members of underrepresented groups in STEM. Canning et al. [74] examined the possible effect that faculty members' beliefs about intellectual growth and ability might have on the performance of students who enroll in their classes. They explored the performance of over 15,000 students in a variety of STEM classes taught by 150 faculty, who were characterized as espousing either a growth mindset (a belief that intellectual ability is malleable and can be improved) or a fixed mindset (a belief that ability is fixed and cannot be further developed) (cf. Dweck [75]). Students who were enrolled in the classes of faculty with a fixed mindset performed more poorly as measured by grade point averages. This negative outcome was particularly evident for URM students. In contrast, students who were in courses with faculty espousing a growth mindset performed better and the performance gap between overrepresented students and URM students was narrowed by almost half. Fortunately, as Canning et al. point out, institutions may have an opportunity to mitigate the negative effects of fixed mindset espousal in their faculty through faculty-centered interventions illustrating the value of communicating a belief in growth mindsets to their students.

We, as faculty members, must be willing to take risks as we explore new active learning methods to enhance the educational experience of our students. Some faculty may be particularly courageous in undertaking change that radically alters the way they teach, such as Pollack [60] described with TBL. Other faculty may prefer to dip a toe in the active learning water before diving in headfirst. Techniques such as Reader's Theater and Think-Pair-Share may be good ways of becoming familiar with active learning approaches since these techniques are relatively simple to incorporate into classroom work. A caveat to consider here is that even simple techniques still require class time, so one has to consider how to best optimize material to be presented and discussed in class, as I have learned in my own courses in which I deployed these techniques.

7.2. Faculty development and support

Investing an institution's resources in its faculty so they can explore and implement undergraduate research experiences, active learning strategies, and inclusive pedagogy across the curriculum is critical in order to ensure that the next generation of college graduates are given the finest neuroscience education backed by discoveries in discipline-based education research. As discussion above has indicated, providing undergraduate students with research opportunities and active learning experiences can significantly enhance the education of STEM undergraduates at a wide range of colleges and universities. Thus, institutions should give neuroscience faculty the time and financial resources they require to undertake the work involved in transforming the way they teach. Listed below are four areas in which such investments should be made:

1) Time may be the most important ingredient in this recipe for success! Providing a course release would provide the time to reinvigorate and reinvent the classes faculty teach using active learning strategies. Sabbatical policies that afford faculty the intellectual space to generate creative approaches for implementing active learning strategies or undergraduate research experiences in their courses and laboratories would accelerate the adoption of these strategies across campuses. Sabbaticals designed to promote teaching effectiveness could also be spent in securing private or federal funding that may affect not only the home institution but may serve as a national model when their extramurally-funded programs are launched and assessed (see discussion below).
2) Providing sufficient financial support to faculty conducting summer or academic year research with their students is of paramount importance in order for faculty to provide a meaningful mentored research experience to their students. This support would take the form of student and faculty stipends as well as funding for supplies and travel to meetings to present their findings.
3) Giving faculty opportunities to share their lessons learned, concerns, or inquiries about teaching with evidence-based practices would be important. These opportunities may range from low-cost bag lunches to fully developed, intensive workshops for which organizing and presenting faculty are rewarded with service acknowledgement towards promotion and tenure, financial compensation, or course release, depending on the significance of the time commitments. At Davidson College, the Howard Hughes Medical Institute (HHMI) through its *Inclusive Excellence Initiative* (www.hhmi.org/science-education/programs/inclusive-excellence) supports such a workshop program (Fostering Inclusivity and Respect in Science Together – FIRST) to promote faculty development through a series of ongoing workshops focused on inclusive pedagogy.
4) Indeed, offering incentives to encourage faculty to seek extramural funding, whether from private foundations such as the HHMI or federal agencies such as the National Science Foundation (NSF), are especially important to accelerate the creation and implementation of innovative teaching strategies at an institution, which may serve as a national model for other colleges and universities to emulate. Funding mechanisms such as the NSF's Improving Undergraduate STEM Education: Education and Human Resources Program could help to transform the educational infrastructure of an institution, but faculty require time, such as course releases and sabbaticals, to undertake the preparation of a competitive grant application. Efforts that faculty undertake to secure funding for pedagogical initiatives should at the very minimum be acknowledged as important steps towards promotion and tenure. Faculty also require adequate support from an institution's office responsible for managing grant application creation and submission; this is especially the case for faculty working at institutions without an extensive history of securing extramural support for their teaching and research activities [76].

7.3. Concluding comments

Undergraduate neuroscience education has been transformed over the last three decades. Given the dramatic growth of undergraduate neuroscience programs across the United States since the 1980s, students clearly have a voracious appetite to learn about the discoveries in neuroscience and faculty are enthusiastically offering them opportunities in classrooms and laboratories to explore in-depth the inner workings of the nervous system. The future of undergraduate neuroscience is bright as inspirational teachers across the country deploy cutting-edge educational strategies informed by a growing body of literature in science education. As faculty responses to the COVID-19 pandemic have shown us, undergraduate neuroscience educators are prepared to meet the challenges of the future head-on to educate the next generation of scientific discoverers, civic leaders, and informed citizens contributing to the greater good. Teaching builds the infrastructure that sustains society and there is no more important a time in recent history to be a member of this noble profession.

Declaration of Competing Interest

None.

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