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Review article

Mini-Review - Teaching Writing in the Undergraduate Neuroscience Curriculum: Its Importance and Best Practices

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ABSTRACT

In neuroscience and other scientific disciplines, instructors increasingly appreciate the value of writing. Teaching students to write well helps them succeed in school, not only because they perform better on assessments but also because well-structured writing assignments improve learning. Moreover, the ability to write well is an essential professional skill, because good clear writing in conjunction with good clear thinking results in increased success in fellowship applications, grant proposals, and publications. However, teaching writing in neuroscience classrooms is challenging for several reasons. Students may not initially recognize the importance of writing, teachers may lack training in the pedagogy of writing instruction, and both teachers and students must commit substantial time and effort to writing if progress is to be made. Here, we detail effective strategies for teaching writing to undergraduates, including scaffolding of teaching assignments, both within a class and across a curriculum; use of different types of writing assignments; early integration of writing into courses; peer review and revision of assignments; mentoring by student tutors; and use of defined rubrics. We also discuss how these strategies can be utilized effectively in the context of multicultural classrooms and labs.

1. Introduction

Instructors of neuroscience ask students to write for a variety of reasons. Some writing assignments intend to improve student learning by fostering student-driven exploration and critical thinking. Other assignments mainly serve to assess how well students have learned some body of material. Writing assignments also help students develop the crucial ability to communicate scientific information with a variety of different audiences, including their future professional peers and members of the general public. Indeed, writing is a key tool that needs to be developed for professional success. These rationales for incorporating writing into our classes - termed “Writing to Learn” [36,48,50] and “Writing as Professionalization” [4] – may seem to be at odds with each other, but in practice they overlap considerably. For example, students may improve their own understanding and gain useful professional skills when they write critically about science. However, it’s also clear that assignments are more effective when their structure is intentionally matched to their intended goals.

For instructors of neuroscience and other sciences, teaching writing well presents several substantial challenges. First, students may enter our courses without an understanding of the value of writing – both as a tool for learning and as an essential professional skill – because it had not been emphasized in secondary school. Second, effective writing is rarely the main learning objective in our courses and therefore teaching writing may seem to interfere with other course goals. Third, many scientists have little experience with strategies for effectively teaching writing. Some neuroscience faculty may be reluctant to incorporate writing into their coursework because few studies have addressed teaching writing in the neuroscience courses. Because neuroscience is interdisciplinary, however, we may build broadly on studies and practices in foundational and related courses in biology, chemistry, psychology, and other fields to develop a roadmap for effective science writing training for neuroscience students.

To have students learn *from* writing while also learning *to* write, a set of best practices that address these challenges has emerged. Well-documented practices include: early integration of writing into courses, scaffolded writing assignments with a coordinated progression of writing assignments across a curriculum, peer-review and revision, mentoring by well-trained student tutors or TAs, and the use of rubrics. Students who are uncomfortable or unfamiliar with writing may not

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otherwise recognize the iterative process of drafting, feedback, and revision necessary to improve writing, hence a more structured process is required [3,9,24,27]. In this mini-review, we discuss these approaches; we also consider some promising areas for further attention, including the value of creative writing assignments and the connection of writing assignments to retention and inclusion. We end with a consideration of how these approaches could be used to involve and include a greater proportion of our undergraduate students in neuroscience.

1.1. *Strategies that are well developed*

1.1.1. *Scaffolding*

Scaffolding has been used successfully in many different educational contexts. This approach involves organized and incremental learning, providing opportunities for students to build skills in order to reach an overarching learning goal. Scaffolding requires instructor-provided support and structure until the student achieves competence. Indeed, the strategy of scaffolding in order to teach has been compared with apprenticeships; students learn professional skills incrementally with guidance [42]. Early and scaffolded writing instruction, supported by sustained and evolving writing practice in upper level classes are crucial to the professional development of the student writer

Proficiency in science requires not only experience in laboratory technique, but also acquisition of skills that convey information and understanding [8,36]. The laboratory-based course therefore, is an important component of a science curriculum, and it is in these courses that the mechanics of research - procedure and communication - can be first effectively taught. While certainly beneficial, writing in laboratory courses is not sufficient as the *only* avenue for students to learn scientific writing. To address this, some institutions have created writing-specific courses, often geared toward preparing for a particular product (*e.g.* senior thesis; a fellowship or grant proposal) [1,35,69]. However, because process and practice are essential to develop good writers, science writing should ideally be woven into a neuroscience curriculum early and often [68]. It has been found that as few as three writing assignments in a course is sufficient to improve students' writing [33], and first-year students are capable of producing original neuroscience grant proposals through scaffolded instruction [32].

1.1.2. *Scaffolding within an assignment*

Structured, multi-step assignments that encourage students to make a sustained effort on a particular writing project may be a particularly effective approach. Walker and Sampson [66] applied an argument-driven inquiry (ADI) strategy in a general chemistry laboratory in which students identify a research question, collect data, develop arguments, and write and revise a report. Students work in groups for portions of the process, developing arguments and communicating them to other groups. There is also double-blind peer-review of early drafts. Because scientific content and process are closely tied to the writing tasks in ADI, students learn by writing as well as improve their writing skills.

Cyr [9] reports on a multi-step writing project in an upper level endocrinology course that teaches students to write concise, detailed, accurate summaries of the literature. Working in groups, students complete several short writing assignments and make a poster presentation. Individually, students write 500-word essays, perform peer review, and synthesize individual papers into a group essay with a 250-word limit. The severe word limits force students to write succinctly. Because peer review in these multi-step projects is done in the context of group work, students may have a greater stake in providing useful feedback, perhaps overcoming some of the problems associated with peer review in other contexts.

At our institution, students engage in authentic research and writing experiences that begin at the introductory level. Kenyon's introductory biology laboratory course serves as a major requirement for the Biology, Molecular Biology and Neuroscience programs. In this year-long course, students practice and refine a writing style that resembles the primary literature. We use a scaffolded approach [9,10,24]. Students first become familiar with basic formats for reporting data in a Results section, then learn to use primary literature to interpret and critique data as in a Discussion section. During the second semester, students learn how to write the Introduction and Methods sections in preparation for writing a research proposal and complete research papers. At all stages of writing, students submit drafts which they are expected to revise prior to final submission. By the end of the year-long course, students are familiar with writing full-length research papers.

The importance of student-driven research in driving authentic writing has been used as an argument against teaching first-year students to write professional full-length articles [36]. This argument is based upon the rationale that students have not experienced authentic research first-hand, and may see writing without a broad knowledge of a field as being artificial, as the products originate from prescribed experiments in a lab manual. Our use of open-ended experimental modules and inclusion of independent research projects at the introductory laboratory level, however, circumvents this argument. The capstone project of our lab course includes an independent research project that students have developed with a mentor, for which they are entirely responsible. The final writing product, a full-length journal article-type research paper, exemplifies the writing skills students can acquire at the introductory level.

1.1.3. *Scaffolding across the curriculum (from intro to upper-level)*

Because graduate programs and companies expect and prioritize professional writing skills, it is important that colleges provide adequate training and opportunities to develop writing in their curricula. This necessitates training that begins at introductory level courses, if students are to have enough time to grow into a professional level of writing expertise [27]. Estimates of lengths of time in which to develop writing competence seem to mirror development of other cognitive skills, and professional writing expertise may require another decade of application in which to develop [31].

In our curriculum, we build upon the scientific writing done in the introductory laboratory with more intellectually challenging assignments in the upper-level curriculum. For example, 200-level classes in Biology and Neuroscience typically include assignments that require the student to read a recent primary research article, briefly summarize its contents, critique the work on its assumptions, methodologies and its interpretations, then expand on the work by proposing several questions and the ways in which those questions could be tested. 300- and 400-level classes typically take this further by asking students to summarize larger bodies of literature in reviews, or as parts of mock grant proposals [27]. The capstone Senior Exercise required for graduation in Biology is a mini-review on a topic of the student's choice, while in Neuroscience, students write a mock NSF Graduate Research Fellowship application along with an article geared toward a lay audience that is compiled and published in an annual "magazine" [Fig. 1]. The emphasis placed on writing in our curriculum has led to substantial success by our graduates with numerous NSF Graduate Research Fellowship winners, including a recent recipient who submitted her application as an undergraduate.

This type of scaffolded approach to writing in a curriculum requires, at minimum, a departmental decision to make writing a priority, as well as agreement across and support among the departmental faculty in its implementation. Better yet is if teaching writing is part of the institution's educational goals, supported by a Writing Center staffed with people who are conversant and trained in scientific writing, as well as other types of support services (*e.g.* extra TA's to help students with writing, workshops for faculty on teaching writing). Last but not least, both teaching writing and learning to write need to be rewarded with positive performance and promotion reviews for the faculty, and better grades for the students.

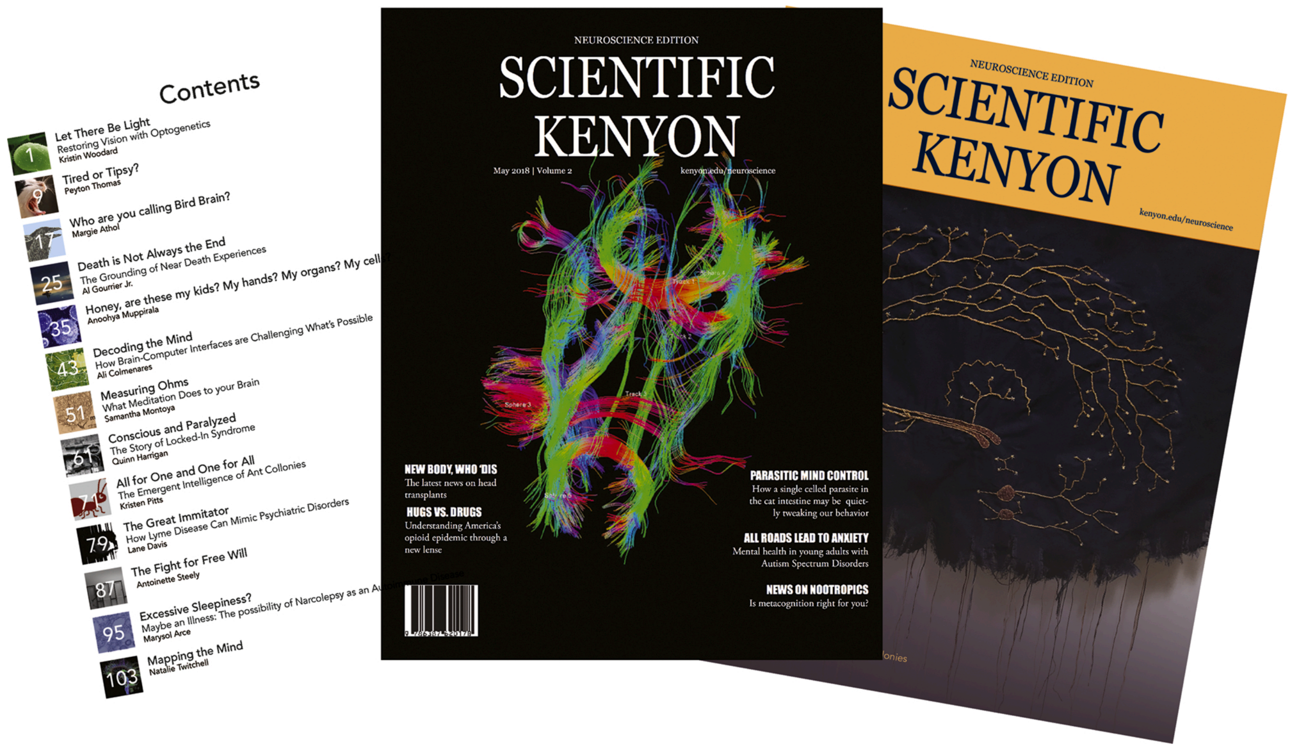

Fig. 1. A table of contents page and covers from recent issues of *Scientific Kenyon: Neuroscience Edition* produced by senior students in the Neuroscience capstone class at Kenyon College.

The scaffolded approach also benefits from instructional materials that students can consult as they move through courses and the curriculum. Several journal articles and a number of outstanding writing manuals are available [18,21,25,43,55,64]. Importantly, these materials cover not only the conventions of scientific writing but fundamental, transferable principles of excellent writing. For example, several of these books draw upon the reader expectation approach (REA) developed by Williams, Gopen, and colleagues and described in *Style: Lessons in Clarity and Grace* [71]. An application of REA principles to scientific writing can be found in the 1990 Scientific American article "The Science of Scientific Writing" [17]. Additionally, scientific writing manuals increasingly emphasize the importance of storytelling in scientific writing. This approach is evident in Schimel's *Writing Science* [55] as well as books by Olson that apply Hollywood storytelling principles to writing about science [39,40]. While some of Olson's suggestions are more appropriate for writing aimed at general audiences, others can be effectively applied to writing for scientific audiences.

1.2. Writing and Reading Exercises

Assigning exercises that teach a specific aspect of writing can be an effective approach. An advantage of such exercises is that students learn about writing in a setting that does not require the instructor to carefully read and give feedback on written papers. Additionally, a whole range of writing issues can be addressed rather than only the ones that happen to manifest on a particular writing assignment. These exercises often take the form of passages that students are expected to evaluate or revise. For example, Robinson *et al.* [52] designed a revision exercise in which students evaluate 12 items - 10 writing passages, one figure and one table - that contain common errors (or are okay as is). In this way, students learn to identify and correct common mistakes. In a paper explaining a curriculum-wide writing instruction program, Stewart [60] points out the value of an assignment that asks students to revise an abstract that contains many common writing errors. Yang [73] used a similar approach to teach students about plagiarism. Students were asked to identify specific kinds of plagiarism in example passages, then to revise the passages to avoid plagiarism. Next, they drafted their own examples of plagiarized passages, then again revised them into proper form. Exercises can also help students learn writing "moves" that are commonly used in scientific papers.

For example, providing students templates that reflect common scientific sentence structures and asking them to fill in their own content can help students begin drafting their own prose [16]. Finally, to write critically about science, students must begin to engage as members of a disciplinary community. Thus, exercises that encourage students to read research articles as rhetorically complicated documents – ones that are both informational and persuasive – can help students write more effectively [15].

1.3. Revising Work

Re-writing is central to all good writing. For scientists, this may mean revising a manuscript, redoing a grant proposal, or refining a letter of recommendation for a student. Interestingly, as teachers, we rarely use this process in our pedagogy, from the primary school level to the college/university level unless the work is so poor that it requires resubmission. However, there is good evidence that multiple edits and revisions improve writing, and that doing peer review followed by revisions can be very effective in "closing the loop." This strategy improves students' ability to see their own writing with an outsider's eye, therefore leading to less ambiguity [51] and better writing [19,27,58,59].

Hyatt et al. [25] point out that instructors often receive student work that resembles "freewriting." Whereas freewriting can be an outstanding technique to start getting words on the page, revision is obviously needed before even a passable draft is reached. Even if a paper requires further revision, students may fail to revise because they don't have time, don't know how, or don't realize they need to. Hyatt et al. [25] map a path towards helping students know how to proofread by cataloging the most common mistakes in student scientific writing; their list could be used by students proofreading their own work or peer-reviewing the work of others.

1.4. Peer Review

Peer review is at the core of the modern practice of science, determining the publication of papers and the awarding of fellowships and grants. Incorporation of peer review into student writing assignments can be found across the sciences from chemistry [8,35,65] to biology [19,20,27,37,58,59], psychology [24] and neuroscience [45]. Peer review has been applied to classes from introductory [37,45] and upper-level undergraduate courses [27,45] to the graduate level [35]. For large classes, Russell et al. [54] developed Calibrated Peer Review (CPR - http://cpr.molsci.ucla.edu) which has been successfully used in classes in neuroscience [45] and other disciplines *e.g.*[37]. In some cases, peer review is an optional part of the class done for extra credit [65], while in others, it is an integral part of the class [27,45,58,59]. In most cases, the peer reviews are done by individuals, but Colabroy [8] describes the use of group peer reviews in awarding "funding" to student proposals in an undergraduate biochemistry course.

Students need feedback in order to learn to revise their own work. In their evaluation of a curriculum-wide writing instruction program, Stewart et al. [60] identify the opportunity to receive feedback from a TA on a draft as one of the most effective activities. However, giving feedback can be time-consuming for instructors and TAs. In this context, peer review seems like an attractive approach. If it works, students receive helpful comments on their own work and gain practice in giving feedback to others. Unfortunately, there are many challenges to making it work well. First, students are not experienced writers, so their feedback may be unhelpful or even incorrect. Second, students don't have an intrinsic stake in providing useful feedback to other students, so they might not take it seriously. Third, peer review is time-consuming [27] especially since it must include training of students [35]. To address these challenges, instructors can provide students with opportunities to practice peer review, offer clear criteria for reviewers, and ensure that each student receives reviews from multiple peers [27,45,66]. Although instructors report well-conducted peer review to be effective in improving writing, reports from students are mixed, with some finding it too time consuming, unfair, or unhelpful [45,66].

Controlled studies assessing peer review as a teaching instrument are relatively rare, but they have been done for undergraduate thesis writing [51] and for a large introductory biology class [37]. Both find that peer reviews improve student performance. The perceived benefits of peer review include exposure to examples of both good and bad writing [27,57–59] as well as the ability to start seeing their own writing with an outsider's eye [27]. A particularly useful strategy may be to have the students assess their own work after having peer reviewed the work of others [37].

1.5. Writing for a General Audience

At Kenyon, assignments at several curricular levels ask students to write papers with general audiences in mind. In some 200-level Biology courses, we assign "News and Views" multi-step projects that require students to write two essays about a research article - one intended for general readers ("News"), the other intended for a scientific audience ("Views") - and then to revise both essays. We find that asking students to write with the general reader in mind often forces them to understand scientific concepts in a deeper way than would be necessary if a scientific audience was the focus. Moreover, we notice synergy between the two essays. Students often draw upon what they've learned in the Views essay to strengthen their News essay, and *vice versa*.

In our capstone Neuroscience course (NEUR471), students write a popular science article similar to those found in *Scientific American* or *The American Scientist* magazines. These articles are professionally bound at the end of the course to create a magazine called *Scientific Kenyon: Neuroscience Edition (See* Fig. 1*)*. Several of the writing and inclusive practices discussed in this review are employed in this assignment, no doubt contributing to its success. The process begins with each student choosing a topic based on their individual interests (*more topic choices; thoughtful participation*), presumably playing to their individual strengths (*asset-based approach*), perhaps increasing their motivation and self-efficacy beliefs [13] leading to a better end product. Each student makes a "pitch" of their topic for inclusion in the magazine to their classmates, who offer feedback, suggest modifications, and can even reject a topic *(collaboration*; *peer review*), although the latter is rare. A successful pitch is followed by a written and orally presented annotated bibliography, and several written drafts aided by oral presentations and group discussions (*peer review, scaffolding, and revision*). The final version also receives critical feedback from both student peers and faculty, and is revised before inclusion into the magazine (*collaboration, peer review and revision*). The faculty member mediates all discussions and presentations, making sure that peer interactions, critical analyses, and discussions are respectful and productive and that all voices are heard (*welcoming space*). The magazine has been a great success; so much so that we have anecdotal reports of some students beginning to think of their magazine topic as early as the junior year. While this project comes at the end of our students' college careers, these principles can be applied successfully to writing projects throughout the curriculum.

Educators have also explored the use of creative writing to improve learning of scientific content in basic science and health professions courses [22,28,30,56]. Pollack and Korol [44] asked students in a seminar course to capture complex neuroscience material in the highly condensed haiku format. They report that it improved comprehension, helped students communicate complicated concepts, and – more broadly – connected their science course to the arts. At Kenyon, members of the English and Biology department have team-taught a Science Writing course in which students write creative pieces with strong scientific content. Our initial observations are that writing creatively about science causes students to engage with science from a different perspective. Whether or not it improves students' technical writing as well is an important but unanswered question. Another question worth pursuing is whether creative writing assignments improve inclusion and retention in the sciences by offering students who enjoy and excel in creative literary work a pathway into scientific material.

2. Mentoring and the Use of Teaching Assistants

Peer mentors and TAs can reinforce what students learn from faculty about writing and provide frequent, individualized, near-peer feedback [10,32,69,70]. Thus, peer mentors and teaching assistants can make a productive writing assignment feasible in a large course, as the instructor can share the time-consuming responsibility of providing feedback with them. Students who receive peer mentoring not only improve their writing, but also report higher confidence and self-efficacy [34], which are important for persistence in STEM. Furthermore, the benefit extends beyond the student; TAs also report enhanced writing ability as a result of analyzing their peers' writing and providing feedback, similar to the benefits of peer review [7,53].

The benefits to both student and mentor, however, assume that the mentors receive sufficient training to assess students' writing [23]. Mentors need training to properly assess student writing and equilibrate expectations across instructors and assignments. Without training, TAs may primarily assess straightforward structure and form (as with a rubric, see below), which students can often address without a peer mentor. Instead, TAs might work with instructors to co-develop goals and assessments in a course [4]. Alternatively, instructors might coordinate with campus Writing Centers who employ full- or part-time staff, including peer writing mentors [1]. To be effective, the Writing Center should have staff trained specifically in scientific writing and in working with students writing in English as a second language. Writing mentors can be specific to a course or instructor, and therefore familiar with the assignment and expectations. At Kenyon, students who have previously taken the course can serve as peer mentors for the course or provide course-specific assistance through a campus writing center. Students in biology courses can make appointments with members of the BioSquad, a group of students employed by Kenyon's Writing Center as peer mentors for writing assignments. BioSquad students are often hired based on referrals and recommendations from professors who have been previously impressed with students' writing in their courses.

2.1. Rubrics

Rubrics are often used in teaching writing to communicate features of effective writing alongside multiple dimensions of achievement [2]. Instructors can use rubrics as an assessment tool to reduce time burden and, particularly when combined with blind grading, ensure fair and consistent feedback to all students. These factors are particularly relevant to writing assignments in courses with large enrollment with multiple graders [37,63]. Even without detailed point values attached, rubrics outline learning and writing goals to ensure that course objectives are met within an assignment [1,32]. By highlighting learning goals within a rubric, objectives may be standardized across a course and even a department [60,62,66]. Students can also use rubrics as learning tools. By providing a rubric early in the writing process, students have a metacognitive opportunity to improve their writing and to increase their confidence [7,8,63]. Peer review is also enhanced by the use of rubrics, as students receive training in fair assessment of others' work that can then be translated to their own [20,35].

While rubrics can be useful for both instructors and students, caution must be taken so that rubric assessment does not overly emphasize writing mechanics at the expense of reasoning, argument, and creative yet appropriate stylistic elements [12,50,61]. These aspects can be challenging to effectively incorporate into rubric and are especially subject to readers' interpretation [23,62]. Therefore, using a rubric can result in an assessment that prioritizes mechanics. This emphasis can be appropriate for some forms of writing. For instance, in a straightforward written summary of a scientific concept, emphasis on communicating content correctly is appropriate [5]. Similarly, highlighting genre conventions in a rubric, even with low point value attached, can draw the students' attention to areas with typically poor performance [65]. However, even when reasoning is effectively incorporated into a rubric, students may have a "box-checking" mindset inclining them toward style and format elements that are easier to identify and assess [61]. Therefore, to ensure that rubrics are formative tools to holistically improve student writing, the instructor should align the rubric to the goals of the assignment and provide training to both the students and graders for its use.

2.2. Looking forward - Retention and Inclusion: A role for writing assignments

The STEM attrition rate among college students is high [6]. Given the observed benefits, deliberately incorporating writing into the neuroscience curriculum could have a positive effect on STEM persistence. In particular, underrepresented minority (URM) populations continue to trail the general population in STEM fields [38]. Many of the practices identified for successfully teaching writing in the curriculum have also been identified as central to inclusive pedagogy (for review, see Johnson, 2019 [29]). A sense of inclusion and belonging is important for persistence in STEM student populations [72], a fact that is particularly true for URM populations [46,67]. Because many of the writing practices described above are also practiced as a part of inclusive pedagogy, well-designed writing assignments could help to facilitate student persistence in STEM.

Parameswaram's [41] inclusive writing assignments track closely with the general themes of good writing pedagogy and include: a) "reflect[ing] students' interests and needs;" b) more topic choices, c) goals broken into smaller segments (scaffolding); d) peer guidance and feedback (peer review); e) opportunities to work with others (collaboration). These criteria are also closely aligned with those identified in the literature as inclusive classroom practices [11,14,29,49]. Additionally, Parameswaram states that as part of the process of inclusive teaching he attempts to "connect to students' lives in an authentic way." This approach is perhaps an earlier example of Puritty et al's. [47] suggestion that an important aspect of inclusion for URM scientists is the ability to "bring their whole selves" to the workplace/laboratory. These asset-based approaches [29] to developing students' writing offers the additional benefit of possibly facilitating STEM persistence. It is critical, therefore, that STEM faculty adopt inclusive pedagogical practices, including writing assignments, as a means of encouraging greater persistence of all students in STEM fields.

If the inclusive classroom is to serve as a model for developing inclusive writing assignments, Johnson's [29] prescriptions of the inclusive classroom suggests that such assignments should have/be: a) an asset-based approach where students' assets are emphasized rather than their deficits; b) explicitly stated expectations; c) establishing a welcoming space with emphasis on respectful faculty-student and student-student interactions; and d) promote thoughtful participation [11,29,49]. These practices, applied early and consistently in the curriculum, should benefit all students, and have the potential to facilitate the persistence of URM populations in STEM.

For some faculty, however, large class sizes and other demands may present a challenge to adopting the kind of inclusive writing practices we have highlighted. In such cases, serious consideration should be given to incorporating graduate students and/or advanced undergraduates as integral members of a writing instruction team, trained and led by the faculty member [26,63]. Small sections can be created within the larger class, each led by the teaching assistants who also grade the assignments based on a class-wide rubric [63]. This has the advantage of allowing the faculty member to both incorporate writing and provide meaningful feedback without succumbing to the enormous workload such an approach would normally create. In cases where access to student assistants is also a challenge, the faculty member should consider making use of a peer review system such as the Calibrated Peer Review (CPR) [37,45,54]. In brief, the CPR allows students to use a web-based system to learn to assess short abstracts on topics selected by the instructor. Students are "calibrated" by successfully assessing three online sample abstracts of different qualities for … "content, clarity, grammar and style…" after which they proceed to assess the anonymous abstracts of their classmates and finally, their own writing [54]. Of course, faculty should adopt whatever approach works best for the local situation, but given that even a few short writing assignments have been shown to significantly improve students' scientific writing ability [34], it is clear that some form of writing should be included in the curriculum.

3. Conclusions

Learning to write well confers many advantages to neuroscience students. Here, we review the literature on the theoretical bases for learning to write well and outline some proven strategies for teaching writing in undergraduate lecture and lab classes. Importantly, these best practices are also scalable to large class sizes. Although teaching writing can be difficult and time-consuming, these strategies can decrease the work, and improve student outcomes, including increasing retention across a diverse student body. These strategies will work best with strong departmental support where there is coordination across faculty teaching different courses, supported by institutional resources to aid both the students and the faculty. In summary, we strongly encourage our colleagues to incorporate the teaching of writing into courses as an integral part of the pedagogy.

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