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A PERSONAL VIEW

A student guide to proofreading and writing in science

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Hyatt JP, Bienenstock EJ, Tilan JU. A student guide to proofreading and writing in science. *Adv Physiol Educ* 41: 324–331, 2017; doi:10.1152/advan.00004.2017.—Scientific writing requires a distinct style and tone, whether the writing is intended for an undergraduate assignment or publication in a peer-reviewed journal. From the first to the final draft, scientific writing is an iterative process requiring practice, substantial feedback from peers and instructors, and comprehensive proofreading on the part of the writer. Teaching writing or proofreading is not common in university settings. Here, we present a collection of common undergraduate student writing mistakes and put forth suggestions for corrections as a first step toward proofreading and enhancing readability in subsequent draft versions. Additionally, we propose specific strategies pertaining to word choice, structure, and approach to make products more fluid and focused for an appropriate target audience.

pedagogy; undergraduate

SCIENTIFIC WRITING for undergraduates requires instruction and practice. Resources for developing strategies for teaching writing are available as guidelines and assessments (1, 4, 9, 12, 15, 17–20, 22, 23, 28, 29). Reynolds and Vogel (20) propose an exercise that targets writing precision and detailed verbiage, whereas Tomaska (28) recommends tips in preparing a scientific manuscript. Common within these sources is a recommendation that students proofread their own work, elicit peer reviews, and correct their first drafts before submitting their papers. However, there is little explicit guidance on how to proofread effectively and efficiently. We envision that this paper will be used as a resource for science instructors and students by providing a list of common first-draft student errors accompanied by explanations why they are not acceptable and suggestions for remedies.

The motivation for this paper emerged from two undergraduate courses that require writing: "Communicating Science" for first-year students and "Physiological Adaptations" for students completing studies in their final year of enrollment. In these courses, we employed a number of strategies to improve student writing, including the requirements of submitting multiple writing drafts during the semester and engaging in peer review (7–9, 20, 21). Our observations within these courses, along with feedback from students, revealed frustration with peer review, inasmuch as these assignments were thought to have minimal benefits on the writing process. There was confusion and insecurity about how to review another student's work. Unfortunately, the practice of peer review was not a priority for students relative to other, substantive assignments within these courses (3, 14). Consequently, after 2 yr, we removed the peer review element and relied on detailed instructor feedback exclusively. This strategy allowed for the quick correction of noted errors by students, but we found that instructor input did little to foster a student's ability to generalize and correct similar errors elsewhere in their writing assignments. For instructors, correcting multiple drafts with nearly identical errors reappearing among the majority of students was excessively time consuming. It is from these class assignments that we have compiled our list of the most routine student writing mistakes with recommendations on how to notice and address them, as a general guide for students and instructors alike.

The literature on scientific writing is largely missing a resource for undergraduate students about the basic mechanics and strategies for scientific writing and proofreading (12). Traditional guides for general (6, 25, 30) and scientific writing (10, 11, 15) are intimidating to the undergraduate student from a voluminous or complexity standing. Additionally, undergraduate students majoring in science justifiably prioritize learning other scientific materials from other courses over assignments requiring reading about writing. Consequently, any assignment requiring students to read textbooks or seminal works to improve writing often get short shrift.

This student guide, informed by more comprehensive instructional materials, condenses insights from these earlier works (10, 11, 15, 25, 30) in combination with our experiences on student writing. We provide brief explanations why these mistakes are not appropriate for scientific writing and recom-

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mend quick fixes for the proofreader. We believe recognizing and correcting these fundamental oversights will enhance the readability of early drafts and convey their ideas better. Learning to write well can take a lifetime and is a daunting endeavor. One objective in this paper is to provide a first step for students to gain basic skills and confidence needed to write well using a few easy-to-master techniques.

Certainly, not all instructors will agree with all of our selections for inclusion or suggestions for addressing errors, and this is expected: writing is a subjective process and each person has an individual style. At a minimum, we anticipate this guide will serve as a springboard reference and checklist to assist writers through editing and revising to elevate the quality of drafts early in the process and to stimulate discussion among instructors and peers about writing strategies.

Broad Misconceptions by Student Writers

The goal of writing is to put an idea or information on paper and communicate it clearly to others. The most important aspect of a scientific paper, arguably, is content. For science students, learning what to communicate is as important as how to write it. If a writer has nothing new or interesting to communicate, then how well she writes is not relevant. But poor writing also can undermine, or mask, a writer's ability to communicate his good thoughts. Presenting ideas and information in a manner that conforms to the expectations of the audience is essential to communicating complex and new ideas and information clearly (10). This skill is enhanced by practice, emulating word choice, style, and organizational principles from examples within the literature, and soliciting detailed and consistent feedback from peers or mentors. As a general start, a writer should avoid the following two common mistakes for any assignment.

1. Do not write using the "spoken voice." One of the biggest misconceptions we have observed is the student assumption that, "if I can speak, then I can write." It is difficult for students to turn off their "spoken voice" and turn on their "writing voice." We suspect that this difficulty is the consequence of a lack of routine and sustained formal writing opportunities compared with occasions for informal writing during college or elsewhere. The informal writing styles acceptable for email, texting, social media posts, blogs, or diaries likely encourage the use of spoken voice in students' formal work. Students' written works for the sciences are submitted as hybrids of spoken and written voice, which must be rectified to be acceptable for a science audience and highlights the importance of proofreading.

2. Do not turn in the first complete draft. Writing guides recommend free-writes for first drafts to focus on content without the constraint of style or formality (6, 30). Although it is not always the case, undergraduates often delay paper writing until the final day or hours before the due date. Ultimately, the first draft, which often reads as a free-write, is submitted with errors and spoken language throughout the document. Reading and evaluating a poorly written paper is frustrating for an instructor because it can be difficult to determine whether the bad writing is covering up good ideas or content. If bad writing is the source of the problem, then the student can remedy this by proofreading the paper or enlisting a peer to give comments. Experienced writers understand that producing a badly written first draft is an accepted part of the writing process. This understanding of the process makes it easier to put ideas on paper without constraints, subject to corrections in subsequent versions. Unfortunately, students often feel that it is more expedient to combine these steps; in fact, the added pressure "to get it right" in the first draft may ultimately prolong the entire writing process.

Specific Writing Mistakes and Suggestions to Strengthen Proofreading and Writing

A first step toward becoming conversant in scientific writing is learning how to recognize and redress mistakes that permeate writing. Below we provide an enumeration of specific foibles in syntax or grammar that plague student writing. These culminate as a proofreading checklist for students (Table 1) to generate better written papers in subsequent drafts. This list is also useful for structuring peer review activities, as it provides student peers with a place to begin providing suggestions for peer improvements.

Eliminate . . ., so . . ., colloquialisms, and clichés. There is no straightforward explanation why *so* finds its way into students' papers, but it is often used to link conditional statements. For example, the phrase, . . . *is required for nonshivering thermogenesis, so the body can stay warm* . . . demonstrates how informal spoken language is substituted for formal written communication. *So* and other commonly used verbal expressions, such as colloquialisms and clichés, inadvertently sneak into students' free-write first drafts, emphasizing the need for proofreading to eliminate such mistakes before a paper is submitted. Solution: Reorganize sentence structure and word choice to remove *so*, clichés, and colloquialisms.

Eliminate phrases with empty content. Clauses such as, *Many studies have shown* . . ., *It is well known that* . . ., or *Science has revealed* . . ., often begin student's papers or paragraphs. Understandably, the student writer may be incorporating these "just to get started" writing. This strategy is sound to jumpstart writing, but these vacuous statements should be targeted and removed after the first draft has been completed during proofreading stages. Solution: Remove or

Table 1. *Summary of common student writing errors and recommended solutions*

Common Writing Errors	Recommended Solution
. . . *so* . . .	Eliminate; restructure sentence
. . . *whether or not* . . .	. . . *whether* . . .
. . . *in order to [verb]* . . .	. . . *to [verb]* . . .
If. . ., *[ ]* . . .	*If*. . ., *then* . . .
Though . . .	*Although* . . .
While . . .	*Although* . . .
. . . *to [adverb] [verb]* . . .	Use strategically; . . . *to [verb]* . . .
. . . *when* . . .	Restructure using specifics
. . . *prove/proof* . . .	*support*, *show*, *provide evidence for*
. . . *significantly different* . . .	*significant* OR *different*
. . . *more/less [ ]* . . .	. . . *more/less than* . . .
Prompting thoughts/sentences	Flip/restructure sentence
Ideas in action	Flip/restructure sentence
Empty content	Use numbers/values/specifics
Colloquialisms and clichés	Eliminate
Quotations	Eliminate/paraphrase
Beginning sentences or paragraphs with prepositions	Flip/restructure sentence

substantiate empty content by adding summary detail that provides new information to the reader. Refer to the *Paper format/citation guidelines* section below for suggestions on specific and proper citation formatting of primary research or literature reviews to help avoid empty phrases in writing.

Avoid using vague words to describe quantity or make comparisons. Science is about quantification, and a writer's points are generally strengthened if she presents comparisons through numbers or values. Although using words that allude to quantity, such as *many*, *numerous*, or *various*, is not technically wrong, the precision of written content in the sciences is enhanced by details that reveal specifics to the reader. Additionally, vague words such as *increase*, *decrease*, *up*, or *down* used for comparisons can often be replaced with specific values to provide a deeper understanding on the differences between groups. How numbers, values, or quantifying elements are presented in written form is situational. Clearly, attempting to juggle too many numbers within a sentence, particularly data gathered from physiological systems, can be cumbersome, and presenting group comparisons can often be confusing for the writer. To remedy this, the writer should consider reorganizing the values into a table or figure to present comparisons (10, 11).

Specificity helps establish a baseline for what is "normal," allowing the reader to interpret the meaningfulness of the changes presented. For example, the phrase, . . . *a decrease in circulating cortisol levels to 120 ng/ml* . . ., is meaningless if the reader does not know what is expected as normal or what the value was before experimentation or intervention. Establishing a baseline allows the writer to report how or why the change from this baseline is physiologically noteworthy. Describing this change as a fold or percent change relative to baseline rather than presenting raw values can make the prose less convoluted and generally strengthen the writing. This tactic promotes the discussion of group comparisons by translating raw scores into an interpretable form rather than leaving it to the reader to sort through the data and perform these conversions. This use of summary values also reduces the wordiness of the paper. Solution: If possible, use quantifiable detail (i.e., numbers, values) to substantiate general and vague information describing a change or difference; consider presenting relative (fold or percent) changes from baseline observations to summarize differences between groups.

Do not use . . . more/less . . . [ ] . . .. A qualifying word in sentence such as *more* or *less* is a subtle clue to the reader that the writer is attempting to make some type of comparison. For example, in the sentence, *These findings prompted health agencies to recommend more physical exercise* . . ., the word "more" suggests that the sentence is incomplete and begs the question: more physical exercise *than* what? Although the reader may intuitively know the answer to this question, the writer avoids ambiguity if the sentence is explicit. Solution: Use . . . *more/less* . . . *than* . . ..

Do not use . . . whether or not . . .. Scientific experimentation implies that we are comparing two or more groups to answer a question. Answering this question is dependent on our observations, or comparisons, of groups with and without the introduction of an intervention, and we expect our findings to reveal that something is present or absent. This phrase also is used widely in spoken language as a way to verbalize our either/or expectation in our experiments. *Whether* alone satisfies the conditional circumstances of the experimental comparisons that are being made. Solution: Use . . . *whether* . . ..

Do not use . . . in order to [verb] . . .. Placing "in order" in front of a verb is another example of spoken language permeating into our writing and qualifies as a redundancy. In fact, the overuse of . . . *in order to* . . . in our language makes not using it sound awkward. Unfortunately, although pervasive throughout the scientific literature, eliminating this phrase generates a more succinct and fluid read. Solution: Use . . . *to [verb].*

Do not use Though . . .. *Though* is synonymous with *although* in spoken language, and this interchangeability frequently transfers into our writing. Inasmuch as writing is our formal attempt to use the English language, it is good practice to use *although*, particularly at the beginning of sentences. Solution: Use *Although* . . ..

Do not use While . . .. Similar to the use of *though*, *while* permeates in students' written work. *While* is problematic because it implies that time is a variable in a sentence. As readers, we may anticipate reading about how time was an important component in the points being made within the sentence. If *while* is not clarified because it has been used in place of *although*, then the reader may be led astray about the point of the sentence. Using *while* introduces a potential point of confusion that can be easily circumvented. Solution: Use *Although* . . ..

Avoid using when . . .. This recommendation may appear extreme. However, there are too many ways to use *when* in a sentence, and it is often incorporated incorrectly by the novice writer. *When* is arguably the most frequent and overused spoken word that finds a place in writing because of its strong association with both time and condition. It can be used as a direct or indirect question, as a conjunction referencing the past, present, or future, as a pronoun, and is sometimes confused with "if." For example, the placement of *when* in the example clauses, *Direct adaptation occurs when looking at blind subjects and their reaction and thresholds for pain* . . ., or *When body temperature reaches hypothermia levels, the cardiovascular system* . . ., could have any number of meanings intended by the writer. We contend that there are enough options in English, either through specific word choices or sentence structures, that *when* can be avoided almost entirely. Substituting *when* usually produces a more active than passive prose, and its replacement should enhance the reader's understanding of the writer's points specifying, for example, time or condition. Solution: Situational; contingent on the content. We recommend restructuring sentences and adding details or specifics to qualify replacing this word, such as, *Physiological adaptation in blind individuals is assessed, in part, by their reactions to pain thresholds* . . ., or *The onset of hypothermia (body temperature = 35°C) alters the cardiovascular system* . . ..

Avoid beginning sentences or paragraphs with a preposition. Although there may be writing circumstances that mandate its usage, sentence structure and author voice are stronger if prepositions are not used in beginning sentences. We suspect that this habit is a carryover from spoken language, and we have observed students commonly use *with*, *during*, *under*, *in*, *upon*, *since*, *despite*, *after*, *around*, and *without* at the beginning of written thoughts. These sentences are often a continuation of ideas from earlier parts of the paragraph or paper. Examples include, *With an increase in daylight exposure,* *melatonin production . . .*, *Since glucose is metabolized for thermogenesis, insulin . . .*, and *Besides increasing the rate at which oxygen . . .*. Solution: Rearrange sentence structure or combine with adjacent sentences.

Do not use If . . ., [ ] . . .. The grammatical rules on the "If, then" sentence are mixed, although we have observed that undergraduate students routinely exclude "then" from this conditional sentence. Technically, because it is implied within the sentence, exclusion of "then" is not incorrect. However, we recommend using *If . . ., then . . .* for clarity purposes. Scientific writing is complex, conditional, and exploratory, inasmuch as we often fuse facts and interpretations in written language. By intentionally using *then* in scientific writing, the reader is introduced to natural breaks in the writer's thought process. *If . . ., then . . .* is particularly important for reducing ambiguity if more than two clauses appear within the same compound sentence. Solution: Use *If . . ., then . . .*.

Do not use . . . proof . . . or . . . prove . . .. The misuse of "proof" or "to prove" in student scientific writing is likely the result of the wide misuse of the term in popular culture as well as their association with the judiciary (e.g., *. . . to prove beyond a reasonable doubt. . .*). Although these words are appropriate in creative or casual writing, they should be eliminated from writing pertaining to the life sciences. A proof is a mathematical argument that demonstrates, given a set of premises, that there is one, and *only* one, answer to a problem or an equation. Biology is an empirical science. We can never assume in the life sciences that some outcome will always and definitively occur the same way, and it is incorrect to equate even the most compelling experimental finding as "proof." Solution: Eliminate from writing unless discussing mathematics (or alcohol). Replace *proof* and *prove* with alternatives that are appropriate for the life sciences, such as *show evidence for*, *support*, *accept*, *determine*, *elucidate*, or *reveal*.

Do not use . . . significant . . . without statistical justification. Significant or *significance* have very specific meanings in science and should not be used casually. In spoken language, these words draw our attention to a point being made by the speaker and have become synonymous with "meaningful" or "important." Those who are new to scientific writing may attempt to use the word *significant* to underscore their ideas. For example, the fragment, *. . . hemoglobin is a significant contributor to oxygen transport within the blood . . .*, was written to suggest that hemoglobin is an important protein for oxygen delivery, but the use of the word *significant* can mislead a reader. The reader may associate *significant* to the statistical criterion of $P < 0.05$ or $P < 0.01$. In scientific communication, particularly within a Discussion section, it is imperative to distinguish words associated with quantification (i.e., significant, significance) from qualification, or the writer's interpretation, related to the impact of the finding (i.e., important, meaningful, impactful). Scientific writing usually sequesters *significant* to the Results section of a paper; we should write about why these results are *important* in the Discussion. Solution: Reorganize sentence structure and word choice to contextualized words related to statistics and those associated with interpretation or meaning. The example from above could be simply reconfigured to: *. . . hemoglobin contributes to . . .* or *. . . hemoglobin is an important protein for . . .*.

Avoid the useless modifier. Scientific language is both precise and descriptive and is diminished by embellishments. The useless modifier abounds in student writing. Some nontechnical examples include *tuna fish*, *opened trench*, or *incubate on cold ice*. The useless modifier *significantly different* particularly plagues novice scientific writing. Each word, *significant* and *difference*, is widely used and probably represents the most important words in a scientific paper, because each emphasizes that group comparisons are different and that this difference is statistically enforced (not the result of random error). *Significant/statistical difference* and *significantly/statistically different* overemphasize the difference found in the study and are redundant in scientific writing. Lastly, the writer must decide for the audience which findings are important; these may include observations between groups that are not different statistically. Solution: Eliminate the useless modifier; use *significant* or *different* alone in a sentence. The writer may choose to specify the level of statistical significance or how different the comparisons are by stating the *P* level within parentheticals, for example: *A difference was detected between Group A and B ($P < 0.01$)*. If *significant* is used as a synonym for important, then it should be replaced by a more descriptive term.

Do not directly quote others' words in scientific writing. Modern science is based on the collective efforts of many researchers covering decades, if not centuries, of experimental outcomes. As writers, we must properly contextualize this prior work in relation to our own, which can be difficult. Because students lack confidence and experience using scientific language to condense complex information into a single summarizing sentence, they often defer to the voice of another scientist by quoting his or her words. We acknowledge that paraphrasing is one of the most difficult skills for a new writer of science. Depth of knowledge in a subject, practice using new scientific language, and exposure to others' writings will help avoid the urge to use quoted material. Solution: Summarize the quoted material.

Do not prompt thoughts. There are two general forms of prompting thoughts in scientific writing. One is a lengthy citation before summarizing the findings of that research study. Colloquially, we communicate this notion as "fluff" or "filler" in student writing that can be removed. For example, the wordiness of *In a 1978 study from the University of California on honeybee migration, Smith et al. showed . . .* can be truncated simply to *Smith et al. showed that honeybee migration . . .* by removing the prompt from the sentence's main point. If the reader wants to know more about what Smith showed in her study, then the reader can access those specifics by obtaining Smith's published paper directly. The second example occurs when a writer improperly splits a single idea with two subjects into fragments but the secondary subject is stressed at the beginning of the sentence as an unnecessary introduction. For example, *In individuals with compromised immune systems, macrophages exhibit increased aggression . . .*, the topic is *macrophages* but the stress at the beginning on *individuals* because the student is first prompting from where the aggressive macrophage come. In short, we advocate to begin the sentence with the primary topic to encourage a more active voice by stressing important points. Solution: Remove the prompt or restructure sentence by rearranging clauses; consider starting sentences with main point or in stress position. The result is prose that communicates the same information, but the stress is appropriately placed to focus to reader on the intended subject: *Macrophages exhibit increased aggression . . . in immune-compromised patients*. Additional strategies to address this are addressed in the section on *Flipping* sentences below.

Avoid the split infinitive: . . . to [adverb] [verb] . . .. The grammatical rules governing the appropriateness of splitting an infinitive in writing are vague, but it is likely a case-by-case decision (16). A split infinitive is meant to stress the verb in use. If used sparingly, the occasional split infinitive is acceptable, but routine use of this convention within a paper distracts the reader from the points of the author. We caution against using the split infinitive in scientific writing because, as we stated previously, it is essential that scientific writing is clear, succinct, and direct, even more than fictional or creative writing. Overusing adverbs can change the tone of a scientific paper and distract from the science being presented; ultimately, their frequent use will be met with resistance by the experienced science reader. Solution: Do not over use; replace with *. . . to [verb] . . .* alone.

Avoid the idea-in-action. The idea-in-action is a subtle, sometimes unrecognizable, error that finds a way into our writing and is likely the result of a poor conceptual understanding or casual use during speech. These phrases can slip through our proofreading because the idea-in-action appears to make sense and is not overtly or glaringly incorrect from a grammatical standpoint. For example, *. . . physiology plays a role in adapting to high altitude . . .* sounds fine (verbally) and appears correct grammatically. If this clause was spoken to us by a colleague, then we would "know" what he is trying to say because we understand inherently that physiological systems are required for the process of adaptation. However, physiology is an *idea*, or an abstract noun, specifying a field of scientific study. Therefore, its use in this clause, written or spoken, is wrong. The reader may not pick up on this immediately, but it could lead to confusion, even if the reader is unsure exactly why the phrase does not make sense. Action verbs must be reserved for nouns, such as people, cells, hormones, birds, clouds, or volcanos. The idea-in-action forces the reader to attribute action to an amorphous, abstract noun that cannot possibly perform an action. The confusion is compounded when several nouns are centered around a verb or verbs. Solution: Eliminate the ideas-in-action through revision and reconstruction of sentence structure.

Writing, Proofreading, and Editing Strategies for Consideration

There are several simple strategies that we have proposed in our courses to help students initiate the process of becoming better science writers. The previous section listed common errors and provided suggestions for rewriting. In this section, we provide some tricks related to the mechanics of fixing errors along with examples. The techniques mentioned below have helped students find flow for their writing by providing tips for managing details from the primary scientific literature, understanding what elements of the literature should be summarized, and for organizing their own writing at the whole document, paragraph, and sentence levels.

Use the "search in document" function during proofreading. One powerful proofreading tool that is commonly overlooked is the "search," "find," or "find and replace" function available in word processing programs such as Microsoft Word. We recommend employing the find/search bar to locate specific words of spoken language and common writing mistakes that are listed above. At a minimum, this approach is helpful for initiating proofreading by breaking the process into an explicit set of tasks. Hopefully, once the student begins proofreading following these prescriptions, it will lead to a wider and sustained proofreading process covering other elements of writing.

Knowing your audience. Every reader of science has an expectation to learn something while reading. Typically, good advice for writing is to begin generally and become more specific. Throughout the document, new details are introduced to the reader, but it is hard to know what is too general or too specific. This is a challenge for all authors, but it is especially challenging for undergraduates if the level of expertise of their audience is unknown.

As a general rule, we suggest that students write for the other students in the class: use grade- (or year-) level appropriate facts that are surrounded by new and detailed information. For example, a college student in an entry-level Human Anatomy and Physiology course would likely concentrate on general structure and function to demonstrate an overall mastery of the material from that course. In contrast, a written assignment for a senior level (or graduate) course will expect to delve deeper about a topic. If an advanced student writes about simple bodily structure and function for an upper level class, then he will likely receive lower marks because he is not writing at the appropriate level. The reader will be bored with basic facts because that reader expects to learn at a commensurate level with the advanced course.

First word/sentence. At any level, we recommend the First Word approach to frame the paper from its offset. The first word(s) of the paper establishes the level and focus for the entire document and circumvents the writer's need to pare down to the appropriate level where he or she will eventually want to be. Specifying a paper's topic with the first word(s) helps to focus the reader and writer equally. The First Word rule forces the writer into a framework of the paper immediately, but the writer should not begin too broadly. For example, if a student begins a paper with, *The human body . . .*, then there are an infinite number of directions the paper can take, including gross vs. microanatomy, physiological vs. behavioral, molecular vs. systemic, and the internal and external variables that can impact the human body.

For example, *Skeletal muscle size, phenotype, and composition are regulated, in part, by the nervous system* (13), establishes the type of tissue about which the reader will learn and sets an additional agenda for other topics that will be discussed within the document. The remainder of the introductory paragraph, and introduction as a whole, is meant to add summary detail surrounding the general topics from this first word/sentence. The contextual framework of the entire paper is set for the reader with the first word, and the writer avoided the task narrowing the broad-based *human body* generalization to the appropriate level of *skeletal muscle* for the paper.

Flipping. A regular piece of advice given to students is to consider flipping sentences, which is encouraged during the proofreading stage. This advice is meant for students to think about the structure of their document and help create a more fluid and active written voice. Flipping involves moving a clause that appears in the latter half of a sentence to the beginning of that sentence. This is an excellent proofreading strategy for finding and eliminating ideas-in-action, split infinitives, passive voice, and the use of *so* and *when*. This process usually forces the student to rework the entire sentence structure, because subject-verb agreement is generally improved with this edit (10).

Gopen and Swan (10) advocate placing the most important information on the "stress position," which occurs at the end of the sentence. In our experience, students naturally follow this notion and reserve their main points for the end. Rigorously following this rule can generate a conundrum for the student writer: what should be written before the main point? The result in students' writing is often an unnecessary repetition of old information found elsewhere in the paragraph or uninformative prompts (e.g., "fluff"). We contend that strategically flipping some (not all) sentences during proofreading ultimately improves clarity. Moving the stress position to the beginning of the sentence forces the novice writer to modify verbiage and tense that usually results in a more succinct and active voice. It creates a succinct characteristic because superfluous, and wildly broad, information that prefaces the main topic of the sentence (e.g., *The human body is . . .*) is eliminated. It also reduces the quantity of passive voice within the document inasmuch as the writer is forced, through this technique, to write directly and actively about the points being made. The simple examples below highlight the concept of flipping.

EXAMPLE 1. *Original*: During the summer months, Antarctica experiences twenty-four hours of daylight, so the circadian rhythms will be disrupted.

Flip to main topic and add detail: Human circadian rhythms are disrupted during the Antarctic summer months as a result of continuous exposure to daylight.

EXAMPLE 2. *Original*: When exposed to extreme cold, peripheral vasoconstriction will occur to decrease heat loss.

Flip: Peripheral vasoconstriction occurs to decrease heat loss during exposure to extreme cold.

Not all sentences can, or should, be flipped, but this strategy can get the student thinking about structure, content, word choice, and emphasis. Readers often require reminders of content appearing earlier in the paper, and readers benefit from well-constructed segues. However, if the main (stress) point of the sentence is obscured because there is too much going on in the sentence, then this trick brings the emphasis in the sentence forward to achieve clarity. Additional discussion and examples related to sentence structure, grammar, and technical style (summarized and encapsulated as "flipping" here) are expanded in chapter 4 of Hofmann's excellent work (11).

The clause 1 [result], clause 2 [interpretation] rule. Scientific writing is difficult because the writer must handle, often simultaneously, scientific theory, methodology, results, and interpretation. The standard and well-known IMRAD (e.g., Introduction, Methods, Results, and Discussion) paper structure, in part, helps with this organization (24), but dealing with these concepts in a short-written space is hard. Often, the novice writer will use one sentence to discuss a result or scientific finding and the next sentence to interpret the importance of that finding for the reader. Technically, this is not incorrect, but it leads to unnecessarily long manuscripts because words and phrases are repeated between these sentences to maintain clarity. We suggest fusing separate sentences, when appropriate, to produce more cohesive and clear prose and reduce overall wordiness, particularly in a Discussion section.

It is the writer's job to interpret scientific findings for a reader. It is the reader's job to decide whether she agrees with the writer's interpretation (10). Additionally, the writer must relate the findings to the literature as a whole: does it agree or disagree with earlier work? To interrelate both results and interpretation, we recommend that the first clause of a sentence summarizes the results, and the second clause interprets the findings for the reader. In this way, the writer establishes continuity between results and the meaning of those findings and lowers the risk of confusing the reader.

The results presented in the first clause may be summarized as findings from "the current study" (or others' work), which is then followed by "what" or "how" those findings are important (from the writer's interpretation).

EXAMPLE 1. *Original: Sentence 1[summarized result]. Sentence 2 [interpretation].* At 3 days (d) postfemoral artery occlusion (FAL), NPY$^{+/+}$ mice plantar foot perfusion returned to 75% of the nonligated hindlimb, while NPY$^{-/-}$ mice increased to only 50%. This decreased perfusion observed in NPY$^{-/-}$ mice suggests a diminished capacity for collateral vessel enlargement.

Revision: Clause 1, clause 2. Delayed early improvement of hindpaw perfusion observed in NPY$^{-/-}$ mice 3 days after FAL suggests reduced collateral enlargement (26).

EXAMPLE 2. *Original: Sentence 1 [summarized result]. Sentence 2 [interpretation].* Eating a diet high in fat and sucrose reduces wheel running distances from the animal's highest values when compared with rats that consumed a diet that was only low fat [insert references]. This suggests that the food's ingredients can affect how much animals exercise in a day.

Revision: Clause 1, clause 2. Consumption of a diet high in fat and sucrose blunts daily voluntary physical activity in rats compared with rats that consumed a low fat-only diet [insert references], suggesting that diet composition impacts the magnitude of physical activity during a 24-h period.

Paper format/citation guidelines. Any formal writing endeavor will contain guidelines for the writer. This may come in the form of a rubric from the course instructor (1) or a long description outlined by a scientific journal, usually subheaded in a "For Authors" section on journal websites (2, 5). Following these guidelines is required. A thorough and well-cited reference section is generally required as well. The format and style required for each citation used within the body of the paper and in the reference section at the end should be followed exactly as specified (2). For instance, with some styles, the author's last name and year are used within the body of the paper, such as . . . *are believed to be ubiquitous within the cell (Fisher et al., 1986; Jones et al., 1993)* . . .. Other instructions call for the use of references as numbers that correspond with its position within the reference section . . . *have demonstrated an inhibitory effect on signaling (9, 13)* . . ..

How, or where in the sentence, to use a citation can be a challenge for the novice science writer. A writer should cite other studies or sources to inform the reader of, and attribute credit to, the study's author(s) and publication responsible for establishing the information. Citations are incorporated into a paper if specific information has been retrieved. Information identified from a textbook or that which is considered "textbook" or common knowledge (e.g., . . . *hemoglobin binds oxygen* . . .), should not be cited. However, if the common knowledge material is specific to a subspecialty and a description of these specific processes are required (e.g., the steps to angiogenesis), then a citation would be warranted. Finally, specific recommendations for scientific notation, statistical communication, and numerical presentation should not be overlooked (5).

Summarized vs. specific detail in the IMRAD sections. Student papers, particularly at the undergraduate level, often do not require the IMRAD structure generally expected for scientific manuscripts because it is too difficult to conceptualize, conduct, summarize, and write about an experiment in a one-semester course. IMRAD-based assignments may be limited to graduate students or undergraduates who have had several years to conduct and prepare a thesis. Although the tricks specified in this section are tailored for the IMRAD manuscript, they also can be applied more generally to other writing efforts. If, for example, a student is writing a 10- to 12-page review of the literature, then the student writer could incorporate the points pertaining to the Introduction and Discussion made below.

The components and framework of the IMRAD paper have been presented elsewhere in great detail (24, 27, 28), including the attributes, mechanics, and approach for each section. Below we will touch briefly on these sections and provide recommendations that help for the synthesis of data from an experiment, from other literature sources, and how to fuse them together.

A general rule to follow is that the Introduction and Discussion deal with summarized detail, whereas the Results reveals specific, or exact, information about the experiment while ignoring information, or numbers, from other references. Unlike in the Discussion, where the writer may choose to compare her experimental outcomes to previous findings, the Introduction summarizes the literature and qualifies the information without the use of numbers. The Introduction of a paper is meant to build the theory that will be tested by the experiments reported in that paper; the Results and Discussion are reserved for quantification and comparison.

The Results is exclusive for the values generated within the reported experiment. These values are meant to be exact, compared statistically, and reported with dry brevity. Generally, there should be no reference or discussion of findings from other studies.

The Discussion deals with the interpretation of experimental findings in the Results. It can compare studies quantitatively, although this should be approached in a selective and specific manner. Here, it is the writer's job to synthesize information from multiple sources and determine how his findings best fit in the context of that scientific story. For example, the writer may report that his results showed an increase in heart rate, but this increase is not as robust as what others' studies have demonstrated in the past. Rather than reporting specific values from previous studies and comparing them to the current findings, the writer should contextualize them for the reader. For example, we present hypothetical data from three fictitious studies that show changes in heart rate after "pre" and "post" conditions (Table 2). The "specific data" in the Results were then reworked into summary forms that could then be used in either Discussion or Introduction sections of a manuscript. The findings in each paper have been transformed (Levels 2 and 3 Summaries) making them easy to compare and less bulky to write about than the specific values. Example sentences below depict how these levels are incorporated into written form in different sections of the same hypothetical IMRAD manuscript:

> *Introduction*: Aerobic exercise elicits an increase in heart rate [insert references].
>
> *Results*: A significant increase in heart rate was detected between pre- [74 (SD 5) beats/min] and postexercise [99 (SD 8) beats/min] ($P < 0.043$).
>
> *Discussion*: Our findings indicate that heart rate is elevated during aerobic exercise, which is likely attributed to an increased oxygen demand from working muscles. This finding is consistent with others [insert references], although the magnitude of the increase in heart rate shown in the present study (33%) was less than in previous work (51-54%) employing similar methodological strategies.

Taken together, scientific writing must be tailored to the audience. How the data are summarized or specified and reported to the reader is dependent on the IMRAD section.

Perspective

Students are often perplexed and do not understand why their scientific writing does not meet the standards of their professors. They likely have never received formal instruction about how scientific writing differs from other styles and why other approaches are generally unacceptable for science. Here, the experienced writer may find many of our observations and recommendations on student writing intuitive; this intuition emerges from years of writing practice or previous instruction from classic works (6, 10, 11, 15, 25, 30). In our experience, we have discovered that even one lecture on these writing strategies improves student understanding of how to rethink their approach to writing about science. In fact, it is not uncommon for undergraduate students to begin critiquing pub-

Table 2. *Hypothetical means (± SD) and summary levels from three comparative experiments*

	Comparative Study 1: Heart Rate, beats/min		*Comparative Study 2:* Heart Rate, beats/min		Your Study: Heart Rate, beats/min		Suggested Manuscript Section
	Pre	Post	Pre	Post	Pre	Post	
Specific data	63 (SD 2)	97 (SD 12)	71 (SD 6)	107 (SD 16)	74 (SD 5)	99 (SD 8)	Results
Level 1 summary (whole number)	63	97	71	107	74	99	N/A
Level 2 summary (absolute change)	34		36		25		Discussion
Level 3 summary (relative change)	54%		51%		33%		Discussion
Generic finding	Increase in HR		Increase in HR		Increase in HR		Introduction

lished writing from a structural perspective before the end of the semester. The editing strategies recommended here, most of which are reemphasizing approaches made elsewhere (6, 10, 11, 15, 25, 30), were compiled to address the most common and repeatedly made errors by undergraduate students. The strategies have been condensed as specific examples here to help students communicate better. Finally, we have observed that our recommendations of Flipping and the Clause 1, Clause 2 Rule have yielded the greatest improvements in students' written work within one semester because these tricks help to initiate proofreading and correcting of first drafts. At a minimum, we attempt to introduce writers to the technical process of scientific writing and how to proofread such work. Hopefully, it provides new science writers with more direction as they can more critically discern writing from the literature and emulate styles of good writing to augment their own written communication.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

J.-P.K.H. and E.J.B. conceived and designed research; J.-P.K.H., E.J.B., and J.U.T. interpreted results of experiments; J.-P.K.H. prepared figures; J.-P.K.H. and E.J.B. drafted manuscript; J.-P.K.H., E.J.B., and J.U.T. edited and revised manuscript; J.-P.K.H., E.J.B., and J.U.T. approved final version of manuscript.

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