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Teaching Tools and Strategies

A Strategy for Teaching Undergraduates to Write Effective Scientific Results Sections

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Abstract

Most undergraduate instructors would agree that learning to write about data in the style of a scientific research paper is a worthy goal for their students. However, many hesitate to tackle the challenge of teaching scientific writing in their laboratory courses. This hesitation is often due to dissatisfying outcomes from writing assignments, especially given the effort required to provide feedback on student writing. To make writing assignments more manageable and productive for both instructors and students, I have developed a "formula" for writing a standard scientific Results section: the "WHY, HOW, WHERE, WHAT, SO WHAT?" strategy. Introducing students to this formula, helping them to recognize it in published papers, and asking them to implement it in writing about their own experimental data provides a learning scaffold that significantly improves student writing outcomes. The Results section is the heart of any research article, and the quality of its execution provides a measure of students' understanding of experimental questions and procedures as well as their ability to analyze data and draw logical conclusions. Learning to craft a well-written Results section develops general organizational and communication skills that students can apply to other forms of writing and to oral presentations. Thus, it is a valuable experience regardless of whether students may ever actually prepare a manuscript for publication, and it is beneficial when used alone or in combination with assignments that also teach the writing of other sections of a research article.

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INTRODUCTION

Communicating experimental results to other scientists and the broader world is a key part of the scientific enterprise. Therefore, developing students' scientific communication skills should be an explicit goal of undergraduate degree programs in the sciences. Unfortunately, most undergraduate laboratory courses devote little time to teaching students to write in the scientific style. The barriers to implementing a strong scientific writing curriculum within major curricula in the sciences are many. Instructors may feel that writing instruction is better left to the writing "professionals." They may find it difficult to fit writing instruction into laboratory schedules crowded with a long list of techniques and concepts that are "supposed" to be covered in their courses. They may be daunted by the prospect of grading written assignments that can often be quite disappointing when students are just starting out.

Effective communication skills, including writing, provide a competitive edge in the job market and are crucial for obtaining research funding (1, 2). However, most undergraduate students cannot write effectively without explicit training. In general, students who read more, write better (3), but merely assigning more reading will not guarantee improved writing. Deliberate instruction in both reading and writing are required (2, 4). Koen has described a semester-long approach to modeling the process of analyzing and communicating scientific data in an upper-level environmental science course (5). His method deconstructed the writing of a scientific paper into three phases: figure preparation, description of data in a Results section, and drawing conclusions in a Discussion section. Along the way, students discussed decisions related to each phase using their data set and examples from the literature, engaged in peer review, and generated multiple drafts. Koen noted that this approach succeeded in increasing students' understanding of the scientific writing process, but that there was still progress to be made in helping students connect their writing experiences to other aspects of their science education (5).

One study examining factors that influenced student success in scientific writing found that the only accurate predictor was prior scientific writing experience; neither the number of college-level writing courses, exposure to a technical writing course, nor the number of years of study had any effect on the ability of students to write either a persuasive paper for a general audience or a research proposal (6). Students need practice, and it is up to science instructors to require students to write in their classes and to seek the best ways to teach them to write effectively. Other studies have demonstrated that an explicit focus on building students' scientific writing abilities also improves students' critical thinking skills (7, 8), their ability to read and understand scientific literature (9), and their overall success in the biology curriculum (10). Thus, for multiple reasons, there is a real need for practical tools to facilitate scientific writing instruction in undergraduate courses at all levels.

Like Koen (5), I have found that students make the most progress in their writing when assignments are broken into small chunks. Rather than assigning a complete lab report, I ask them to prepare sections one at a time, providing instruction related to each section along the way. In my introductory courses, students write different sections about different experiments, while in my upper-level courses they write about a semester-long project, eventually assembling a complete paper. When discussing any research study, it is essential to understand the purpose, the process, and the findings. A successful Results section weaves together all three of these aspects, so it is the first section I assign to introductory-level students.

I have developed a simple "formula" to teach students how to write an effective Results section, I use this formula in all of my laboratory courses, but I focus here on its implementation in an introductory cell and molecular biology course. In this course, students measure the effects of different variables on the rate of phagocytosis in the freshwater ciliate, Tetrahymena (a set of experiments based on a lab series described by Bozzone and Martin (11)). I teach the Results Formula in the fourth week of a 12-week semester, after the students have acquired their Tetrahymena data sets. I, and others who have used my approach, have noticed significant improvement in students' ability to write about their results when we have used the formula. Our preliminary survey data (unpublished) also indicate that students find it to be a useful learning tool.

THE RESULTS FORMULA APPROACH

The Results Formula consists of five questions students can ask about any experiment (Figure 1).

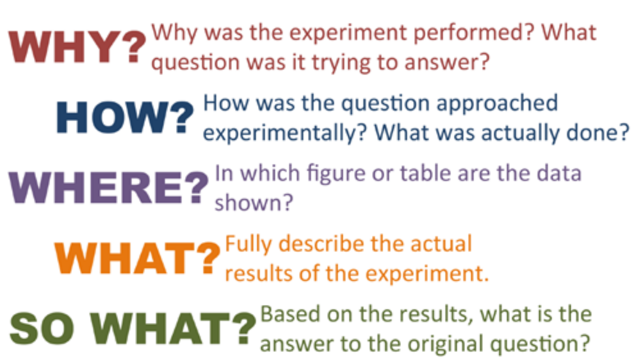

Figure 1. The five components of the Results formula. If students make sure to answer each of these questions in the order listed, they will have written a clear, concise, and complete Results narrative.

When assembled in order, the answers to these questions generate a clear, complete, and concise Results paragraph describing the experiment. To familiarize students with the formula, I first ask them to identify the answers to the five questions in a paragraph from the Results section of a published research paper. In my introductory course, I use an article about selectivity in Tetrahymena phagocytosis as the published example (12). This article is freely available (see weblink in Reference list), and answers for the paragraph that I use are provided in Supporting File 1. Students work in pairs or small groups to examine the paragraph; once they are done, I ask for volunteers to share with the class how they have dissected the sample paragraph, and together we create a color-coded version of the paragraph that highlights the different parts of the formula. The students are then asked to answer the same set of questions to write a Results paragraph for an experiment they have conducted in the course lab.

The first question students must answer is "Why?"— what question were the researchers trying to answer with their experiment? I emphasize that this question should be the real question, not an artifact of the tools used to answer it. For example, some of the students in my course use the actin inhibitor cytochalasin B to determine whether the actin cytoskeleton is important for phagocytosis in Tetrahymena. Their "Why?" for this experiment should not be "To determine the effect of cytochalasin B on the rate of phagocytosis" but rather "To determine the role of the actin cytoskeleton in phagocytosis." The "Why?" is usually just a phrase that is followed by the "How?", completing the first sentence of the Results. Students sometimes need reminding that the Results narrative should be written in complete sentences; they can't just write the phrase stating the "Why?" and add a period at the end!

Answering the second question, "How?", means describing what you actually did to perform the experiment. I try to convey to students that this answer does not need to be as detailed as in a Materials and Methods section, but should give readers sufficient information about the experiment to allow them to interpret the data. When left to their own devices (i.e. when they are not given or do not pay attention to the formula), students often jump straight into describing the data without saying anything about why or how those data were acquired. They may assume that, since I am the audience and I know what they did, they don't need to say it. Alternatively, they may not really have a firm grasp on what they actually did, as in the case of a student who tends to defer most of the hands-on procedures to his or her lab partner. Writing the answer to "How?" gives students practice summarizing a procedure and helps them make connections between their experimental question and the data they collected.

Once a student has plugged the "Why?" and the "How?" into the first sentence(s) of his or her Results narrative, it is time to answer "Where?" and "What?" The answer to "Where?" refers to the number of the table or figure that shows the experimental data. Again using examples from a published article, I point out that you can either state the "Where?" at the beginning of a sentence (e.g., "As shown in Figure 1") or after you have described some of the data (e.g., "The cells treated with cytochalasin B accumulated phagocytic vacuoles at a slower rate than the control cells (Figure 1)."). Students will sometimes refer the "the figure below," rather than stating its number; it is important to emphasize that, in a paper with multiple figures, it's crucial to point the reader to the correct one and that they should practice this even if they know they will have only one figure in their particular paper.

The answer to "What?" is the heart of the Results section. When written properly, the answer fully describes all aspects of the data shown in a particular figure or table. I push students to think of the full range of observations they can draw from their data. In the Tetrahymena phagocytosis experiments performed in my introductory class, students compare the average number of phagocytic vacuoles per cell over time following different treatments that relate to their specific question. Thus, they can describe overall trends over time as well as differences between samples at each time point. Again, when left to their own devices, many students will skip the "What?" entirely, simply stopping at the point of stating the figure or table that shows the data. Other students will go overboard in the Results narrative, listing out all of the numerical data shown in a table or a graph in a way that is difficult for the reader to process. Both ends of the spectrum should be discouraged!

The final component of my Results formula is "So what?" In high school, students are often taught the difference between results and interpretation by drawing a hard line between the content of the Results and Discussion sections. In this schema, "What?" belongs in the Results, while "So what?" is restricted to the Discussion. In real scientific writing, however, it's important to connect what you observed in your experiment (the "What?") and the answer to your original experimental question. Thus, the "So what?" is essentially the conclusion of the experiment. Inclusion of "So what?" in the Results is critical, at least in part because the typical paper describes the results of multiple experiments, with the conclusion from one experiment leading to the next experimental question. Continuing with the example described above, a suitable answer to "So what?" would be "These data suggest that the actin cytoskeleton is important for phagocytosis in Tetrahymena." If a student were writing a Discussion for this experiment, he or she might start with this conclusion and go on to compare his or her data to other published data regarding the cytoskeleton and phagocytosis, to suggest the broader implications for other organisms, propose follow-up experiments, etc.

SCIENTIFIC TEACHING THEMES

Active learning

When I teach the Results formula, I first briefly explain the meaning of each of the five questions: Why? How? Where? What? So what? Then, as described above, I ask students to work in pairs or small groups to identify each component of the formula in a sample paragraph from a published research article. This analysis allows the students to see how the answers to the formula questions are synthesized into a complete but concise and easy-to-follow description of the experiment being described. In addition to identifying how the authors worded their answers to the Results formula in the published paper, students should be encouraged to put these answers in their own words (as I did in Supporting File 1). They may even find that they can word the answers more succinctly or more clearly that in the published paper (see notes in Supporting File 1).

Assessment

I require students to turn in a handout on which they have identified the answers to the five Results formula questions in the published example. This verifies that they have interacted with the Results formula prior to trying to apply it to their own writing. When they submit their written Results sections, I grade them using the rubric included in Supporting File 2, which emphasizes the five questions of the Results formula. This rubric applies to the narrative portion of the Results section and also to the figure (with legend) that students must also include. I often teach two lab sections of 18 students each in a semester, and it is not overly burdensome to grade these assignments. With larger numbers of students, it would be helpful to employ teaching assistants to facilitate timely grading.

Inclusive teaching

I make sure that all students are actively working in groups during the science writing workshop so that they all have an opportunity to contribute. Many students are more inclined to ask or answer questions in a peer context than when they are addressing me. Students can be immediately put off by words they do not recognize when they are first asked to read a scientific paper. The Results formula provides scaffolding to lead students through the paper in a less threatening manner, making them realize that most of the material is accessible to them if they approach it step-by-step. Finally, the color-coding exercise I use when teaching the Results formula assists students who are visual learners to better understand the organization of a good Results paragraph.

SUPPORTING MATERIALS

- S1. Results Formula-Results formula sample answers
- S2. Results Formula-Results grading rubric

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