"Assume Nothing, Expect Everything:" Teaching Students How to Write a Scientific Paper

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Alan Gubanich received both an M.S. in Zoology and a Ph.D. in Biological Sciences from the University of Arizona, Tucson in 1966 and 1970, respectively. He became the Director of General Biology at the University of Nevada, Reno in 1970 and continued to be in involved with the introductory Biology courses and laboratories until Dr. Howard assumed those responsibilities in 2000. He started using investigative laboratories and teaching scientific writing in the early 1970's. Dr. Gubanich also teaches Ornithology and Field Ornithology, conducts numerous workshops for public school teachers focusing on investigative approaches to learning, and is very involved with public outreach via the local Lahontan Audubon Society, ElderCollege, ElderHostel, and weekend workshops offered through Truckee Meadows Community College.

Reprinted From: Howard, C. J. and A. A. Gubanich. 2002. “Assume nothing, expect everything:” Teaching students how to write a scientific paper. Pages 361-367, in Tested studies for laboratory teaching, Volume 23 (M. A. O’Donnell, Editor). Proceedings of the 23rd Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 392 pages.

Introduction

Over the years, both AAG and CJH have noticed a number of major problems that students encounter when writing a scientific paper for the first time. Most of these problems are due to beginning students simply being unfamiliar with scientific papers. Students are used to writing papers in other disciplines, with discipline-specific requirements. It takes time for students to break the habits they've acquired from writing non-scientific papers, and learn the requirements of scientific writing. The major problems are: (1) unfamiliarity with format requirements of a scientific report or paper, (2) how to present their data in tabular or graphic format, and (3) awkward and wordy prose.

In an attempt to help students overcome these problems, AAG has written a writing guide (Gubanich 1998) that is routinely used in the sophomore-level General Biology laboratory course (Biology 192). Recently, CJH has supplemented this guide with an on-line document found on the University of Nevada, Reno, Biology 192 homepage (Howard 2001).

Below are examples of some of the assignments used to strengthen student skills in the areas of scientific format, table and figure design, and awkward sentence structure. For a more detailed look at these and other examples, see AAG's writing guide and CJH's Biology 192 homepage.

What is a Scientific Research Paper?

Very early in the semester, students are introduced to the structure of a scientific paper. Students are assigned two papers to read and a set of questions to use to evaluate whether or not a paper is a primary source paper (see below). The students must decide which of the two assigned papers is considered a primary source.

The primary source paper comes directly from a peer-reviewed journal and contains the same sections (abstract, introduction, methods, etc.) that will be required when the students write their scientific paper. The second paper is a review article, usually from Scientific American. We strongly recommend that both papers be reasonably easy for your students to read and that they relate to topics the students will cover sometime within the lab course.

The week after this first assignment is handed out, the students are quizzed on the reading and asked to write down which paper they think is a primary source paper. A short discussion follows and the students are then assigned a second primary source paper that has been annotated. The second primary source paper can be found on pages 28-35 of the AAG writing guide, which discusses key points relating to each section of a scientific paper.

Questions to consider when determining if a scientific paper is a primary source.

1. What is the purpose of the paper? A scientific research paper usually has a stated purpose. Many will state a hypothesis either directly or indirectly in the introduction.
2. Was the research done primarily by the authors? A scientific research paper is a presentation of the author's original work and referred to as the primary source of this information.
3. How was the argument developed? In a scientific research paper, the argument is broken down into organized sections. Most research papers have a methods section that describes how the experiments were conducted.
4. Was other work cited both in the body of the paper and at the end of the paper? In a scientific research paper, other primary sources are referenced to provide background information for the reader and to help support the hypothesis and conclusions of the author. These sources of information are cited both in the text and at the end of the paper.
5. Who is the target audience? A scientific research paper targets a very specific subset of scientists working in this field or in a related field of study. Unlike scientific research papers, review articles are secondary sources and tend to target a broader audience that includes people who are less familiar with the subject. These audiences can range from other scientists to a general audience and any group in between.

6. Did the author convey any feelings or emotions? Typically, there are no feelings or emotions expressed in a scientific paper.
7. What is your opinion of the paper? Scientific research papers may be more dry or dull to someone who is not interested the topic. However, the same paper can be very exciting for someone who is interested in this field of study.

Designing Tables and Figures

Students are introduced to the procedures for designing tables and figures during the third week of the semester. At that time, they have completed a lab that serves as the material for their first attempt at writing a lab report. The students are required to include a table and a figure of their data in the report. The lab instructors discuss the proper construction of tables and figures, using the appropriate sections in the AAG writing guide (Section V, pages 19 - 26). Then the students are given an exercise to help them solidify these concepts. Table 1 and Figure 2 (the last pages of this article) provide examples taken from the writing guide. In these examples, the students are given a hypothetical data set and shown an incorrect table or graph. The exercise asks the students to first describe what is wrong with the table and graph and then redesign them so they would be acceptable for a scientific paper.

Awkward and Wordy Prose

Anyone who has tried to teach beginning students how to write a scientific report knows how wordy (and often confusing) their first attempts can be. Students need considerable practice before they begin to grasp the essentials of scientific style. We emphasize the need for concise, clear, and accurate prose. We give the students examples of poor sentence construction during the fourth week of the semester, just before their first lab report is due, in an attempt to help them avoid such writing errors. The AAG writing guide has a section that contains examples of wordy construction and unintended meanings, all taken word-for-word from previous student papers. Here are some examples:

Examples of wordy construction ("waste words"):

Example 1. "On each of 7 days of the experiment (at approximately 24 hour intervals) a group member came in to check water levels in the petri dishes and measure root lengths of the germinating seeds." (34 words)

Obviously the measurements had to be made by a member of your group, so you don't need to say that - it's understood by the reader, so you can eliminate those "waste words." In addition, you should state what unit of measurement was used when measuring the root lengths. Better example: *"We measured the root lengths (in mm) at 1:00 P.M. daily for 7 days and added water to the petri dishes when necessary." (23 words).* Notice the word "daily" does the work of five words ("on each of 7 days") and "at 1:00 P.M." also replaces five words ("at approximately 24 hour intervals").

Example 2. "We then conducted statistical tests on the data in the form of t-tests to see if our results were significant."

The above sentence uses 20 words to say what could be said in six*: "We analyzed the data with t-tests.*" The reader already knows that if you use a statistical test, you do so to see if your results were significant. Thus, there is no need to say so in your paper. Those are "waste words," so eliminate them.

Example 3. "Among the three different fish we had about 190 different observations." (11 words)
Better example: "*We made 190 observations on three fish*." (7 words)

Examples of Unintended Meanings:
Below are examples of sentences that don't say exactly what the authors intended them to say.

1. *"These four culture dishes were placed in a well-lit room and allowed to germinate and grow for 7 days."* (It sounds as though the *culture dishes* were allowed to germinate and grow.)
2. *"We then measured the rate of root growth to see if the dish nearest to the sagebrush was more stunted in growth than the dish farthest away."* (Again, it sounds as though the *dish* is growing)
3. *"One of the petri dishes in the control group died for lack of water or possibly from..."* (The petri dish died???)
4. *"The mean root length of the Brassica rapa 5 cm from the sagebrush leaves (experimental 1) showed the least amount of growth."* (The *mean root length* showed the least amount of growth? This makes no sense.)

Once we've gone over these examples with the students, we then give them additional sentences (again, from the AAG writing guide) and ask them to make improvements.

Practice

The students are given a number of opportunities to practice writing using the scientific format. The first assignment involves writing a report on the lab exercise. Students are told that the report is a simplified version of a scientific paper with no abstract, a short introduction, a methods section, a results section with a table and figure, and a short discussion section. The students are expected to use the on-line supplementary guide (Howard 2001) when checking their draft for errors. This on-line guide includes a grading rubric that the students can use to determine if their work is poor, satisfactory, or excellent by the standards outlined by the instructor. The students are given one week to turn in this assignment.

Soon after the lab report has been graded and returned, the students are required to write a scientific paper on an experiment they conducted in lab. The scientific paper includes an abstract, an extensive introduction with cited literature, a methods section, a results section with a figure and statistical data, an extensive discussion section that ties his/her research back to literature in the field, and a literature cited section. Writing the scientific paper is easier for the students if they are first given an introduction to the library and information on how to get started writing a scientific paper (McMillan 2001). The scientific papers are turned in one week after completing the laboratory. The papers are promptly graded and returned to the students for a rewrite. This forces the students to review their reoccurring errors and strengthen their writing skills.

The last portion of the semester is dedicated to an independent project. This project lends itself well to both a written proposal and a second scientific paper. Students are required to write a proposal with an introduction and a methods section. They can later modify and incorporate this information into the final draft of their scientific paper.

The second scientific paper is written on their independent projects. Some years we have allowed the students to write group scientific papers, while other years we have required that they write their papers independently. In general, the final product is better written when prepared as a group effort. However, steps must be taken to confirm that all members of the group have contributed to the writing process. One way to ensure this is to assign a section to each person within the group. Each individual must turn in a rough draft of their section prior to the draft being proofread by the other group members. This rough draft is not graded but it does allow the instructor to confirm that each student's contribution has been incorporated into the final paper.

Final Notes

Anyone who has worked closely with students knows that the ideas presented above are just some of the many ways we can work towards improving student performance in scientific writing. Many of our students seek one-on-one help by asking us to proofread their drafts, or ask for assistance from the campus Writing Center. One or two Biology graduate students are hired each semester at the Writing Center to help undergraduates improve their writing in courses such as this one. Future goals include an assignment on plagiarism, and increased tracking of student performance in writing throughout their college career. Ultimately our goal is to train students who, upon graduation, have the background knowledge and competency required for effective scientific writing.

Literature Cited

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Howard, C. J. 2001. University of Nevada, Reno, Biology 192 homepage. Access through the UNR webCT site at *http://webct.unr.edu*, user ID: bio192-guest, password: marmot.

McMillan, V. E. 2001. Writing Papers in the Biological Sciences, 3rd Edition. Bedford/St. Martin's Press, Boston Massachusetts, pages 5-26.

Table 1. Students are provided with an opportunity to test their knowledge of tabular design. The students are given background information and an incorrectly formatted table (A). Students are asked to find mistakes associated with the table (B) and draw a new table following the format outlined in the writing guide (C).

A.

A researcher was testing the effect of a certain growth inhibitor on the germination and root growth of field beans (*Phaseolus vulgaris*). He measured the root lengths (in mm) of 25 bean seedlings treated with the inhibitor and 25 seedlings not treated. Measurements were made every day for 7 days. He then put the data into the following Table:

Day	Root length (control)	Root length (experimental)
1	0	0
2	4.6	4.4
3	15.7	12.0
4	25.6	16.5
5	38.3	20.7
6	43.3	25.0
7	45.0	27.1

FIGURE 1. Root lengths of bean seedlings exposed to a growth inhibitor.

B.

1. Vertical Lines re not used in tables; they all need to be removed.
2. The table should be labeled Table in the title, not Figure.
3. The title goes above the table, not below.
4. The Column headings should be separated from the body of the table by a delineating line.
5. Need to show units of measurement for root length.
6. Sample sizes should be included.
7. The table should include the scientific name of the organism.
8. The length of time the experiment was conducted should be included (optional).
9. Duplication of word "Root length" can be eliminated by placement as shown in correct example.
10. Need to indicate that data is from the <u>mean</u> root lengths.
11. Should include standard deviations (optional).

C.

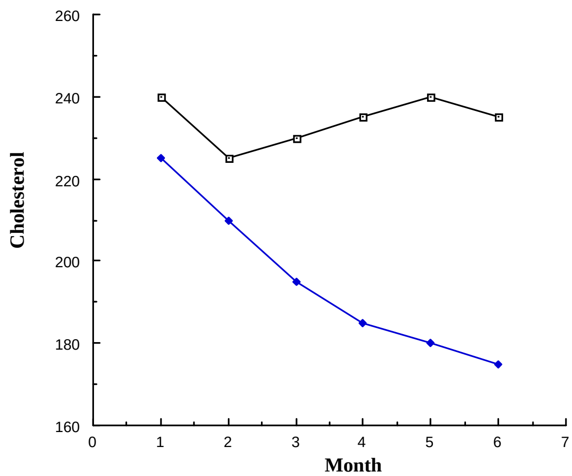
TABLE 1. Mean root lengths of *Phaseolus vulgaris* seedlings exposed to growth inhibitor for seven days.

Day	Root length (mm)	
	control[a]	experimental[a]
1	0	0
2	4.6	4.4
3	15.7	12.0
4	25.6	16.5
5	38.3	20.7
6	43.3	25.0
7	45.0	27.1

[a] n = 25

A. Patients with high cholesterol levels in their blood were divided into two groups of 30 each to test whether or not a new drug (Drug X) was effective in lowering blood cholesterol. One group received the drug, the other a placebo (a fake drug that has no effect). Cholesterol levels (mg of cholesterol per deciliter of blood) of the two groups were measured every month for 6 months. At the end of the study the researcher made the following graph:

GRAPH 1. Patients' cholesterol levels with and without drug treatment.



B.

1. The graph is referred to as a Figure, not a Graph.
2. The Figure title should be below the figure, not above.
3. The unit of measurement for cholesterol levels needs to be included.
4. Sample size should be included.
5. Both lines on the figure need labels; there is no key to indicate which line refers to which treatment.
6. If known, the name of the drug (e.g. Drug X) should be included in the title.
7. Error bars should also be included (optional).
8. Y-axis does not begin at zero (optional).
9. No initial (pretreatment) cholesterol levels are included in the data (optional).

C.

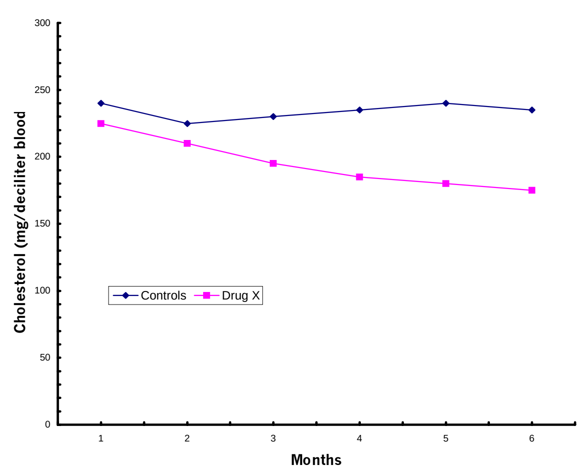


Figure 1. Monthly mean cholesterol levels of patients with and without Drug X treatment. N = 30 for each group.

Figure 2. The example above provides students with an opportunity to test their ability to design a correctly formatted figure (graph). The students are given background information and an incorrectly formatted figure (A). Students fix the problem by listing the mistakes (B) and by drawing a correctly formatted figure (C).