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Directed Writing: Reinforcing Scientific Literacy through the Laboratory Report Process

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Scientific literacy is a fundamental competency for students in undergraduate courses, where students gain the ability to understand the scientific process and to communicate science to others. The generation of a written report that mimics a research article reinforces scientific literacy when students effectively: 1) procure relevant peer-reviewed literature and properly cite, 2) formulate a hypothesis based on previous research in the field, 3) interpret data and format results, and 4) evaluate the connection of the data to previously published work. Separation of the research article into a series of smaller assignments directed students through the expectations for the content expected in each section of a journal article. Students received feedback before moving on to the next segment, allowing time to refine their work, thereby improving skills in understanding the process of scientific research, reading comprehension of scientific literature, and effectively and professionally communicating findings.

Keywords: scientific writing, laboratory report, scientific literacy

Link to Original Poster: **http://www.ableweb.org/volumes/vol-40/poster?art=57**

Introduction

Scientific literacy is the ability to discern the quality and validity of presented technical information objectively. Mainstream news outlets interpret science discoveries published in peer-reviewed research articles to varying degrees of accuracy. Scientific literacy training reinforces a student's capacity to review new claims with objectivity and skepticism of the experimental process. This skill is important for students whose goal is to be a future scientist or health care worker, and we argue that it is vital for every student as they will make decisions about scientific issues throughout their lives. The goal of this project is to teach scientific literacy in a biology lab course using directed scientific writing and regular detailed feedback. This technique allows students to acquire science process skills such as the development of a testable hypothesis, data interpretation, and evaluation of their results in comparison to previously published work. Recent reports recommend changes to science education at the college level that include skills such as training students to think like a scientist (NRC, 2003, Labov, 2004).

Science classes often assign students write-ups or lab reports to communicate findings of a completed lab experiment. However, it is unlikely that there is a common format for these lab writing assignments agreed upon by different sub-disciplines of biology. Substituting these varied formats to one that mimics a peer-reviewed journal article provides commonality that would promote a clear, concise and consistent writing format. In addition to the directed format, the instructions and feedback given by the instructor provide students with a platform to learn and grow throughout their educational path. Students can improve and strengthen their skills in their future science courses in each term, because the student has the potential to improve their writing skills, their scientific process skills, and their scientific literacy.

The implementation of project-based or hypothesis-based lab experiments is ideal for this writing module. The length of this research project may vary from one lab session, to a few weeks, or may span an entire semester depending upon the depth of the project. The length of the experiment is unimportant to the writing project, only the presence of a scientific question and the generation of a hypothesis is necessary. Data has shown that students who participate in these types of labs and learn science process skills improve in other areas of their education such as reinforcement of course content and

improved test scores (Kitchen et al., 2004), and increases student's interest in science (NRC, 2003).

Effective feedback is a vital component of this directed scientific writing process. As students complete each section of their written research article, they receive detailed feedback on their successes and items that need improvement. Feedback styles may vary based on classroom size and instructor time. But it is the frequency and depth of feedback that is most important to improving student writing.

Summary of Directed Writing Assignments

a) Lab Worksheet: Journal Article Identification Worksheet

Assignment: This worksheet contains information on internet sources to search for peer-reviewed publications, guides for search terms and how to identify the best journal article for their research.

Goal: The objective of this worksheet is to have individual students use a literature search to identify references and give them practice with citation formatting.

Student Learning: To be able to generate a hypothesis that is informed by peer-reviewed findings for their introduction section, students need to better understand where and how to identify appropriate journal articles that contain background information for their resesarch. To achieve this student learning goal, the worksheet walks students through different options of internet sites available to search, and how to add search terms would be helpful in narrowing down their literature search. Once they identify the journal article, they are prompted through several questions that help them identify the correct formatting to use the article as a citation. After this exercise, students are then tasked with finding additional journal articles to be used as citations for their research writing.

b) Lab Worksheet: Introduction Section

Assignment: This worksheet contains information on how to effectively relay the background information necessary to understand the reasons for the experiment within a scientific research article.

Goal: The goal of this section is to give students a concrete format in which to introduce: 1) the "big picture" of the project, which is an overview of the topic of the research conducted, 2) the "medium picture" of the project, containing continued background information that is more specific to the experiment itself. This is where students would discuss the general results of the journal articles identified that relate to their chosen research question, and 3) a hypothesis based on previous research in the field.

Student Learning: For students to be able to generate an introduction section that follows a logical flow in which they are tasked with writing specific paragraphs that introduce the big picture, discuss relevant peer-reviewed literature, and can provide a direct and clear hypothesis and prediction for their research project.

c) Lab Worksheet: Methods Section

Assignment: This worksheet contains instructions that help the student to generate a concise methods section that would be necessary for the reader to reliably repeat any experiments performed.

Goal: The goal of this section is to give students an idea of what items are relevant for a methods section and to have that information compiled into distinct sub-sections that describe a certain technique or experiment that was used within the research project.

Student Learning: When students are tasked with writing a methods section, there is a tendency for them to incorporate irrelevant items that are not needed for the reader to interpret or replicate what was performed during the research process. To help the students generate a logical flow of information, this worksheet demonstrates a way to divide the experiments performed into specific sub-sections that will help the student during the writing process. Included are examples of items that are imperative to include in the methods section and those that are irrelevant to the reader. During this process, students will learn how to effectively and concisely generate a methods section.

d) Lab Worksheet: Results Section

Assignment: This worksheet relays information about how to generate an effective narrative and graphical results section in research writing. It reinforces the idea that this section describes the data collected and the mathematical analysis of that data and should not include any data interpretation. In addition, it contains information about how to generate and format tables and figures.

Goal: The goal of this section is to reinforce the concept that there are two main components of any results section in scientific writing that include the narrative that describes the data and the graphical section that illustrates it. The worksheet describes how students can accurately and informatively display their data and how to correctly format and label any tables or graphs generated.

Student Learning: The concept that a results section is not only a series of graphs is something that students need to learn during their time as an undergraduate student in the sciences. This worksheet details what information should

be included in the narrative section and how to break that information down into sub-sections that will relay the information in a logical manner. Students are also given concrete examples of how to make sure the narrative section describes the data while not branching into data analysis.

In addition, this worksheet gives instructions and concrete examples that show how to represent the data that they will acquire during a research project. There are step by step instructions on what labels and titles are imperative for a figure. Students will gain the ability to display data that is easy to interpret and understand with thorough labeling of figures and tables that have informative titles, axis labels, and figure legends. This is important for their current writing and for future instances in which they will be tasked with scientific writing.

e) Lab Worksheet: Discussion Section

Assignment: This worksheet describes how to effectively combine the meaning of the results obtained with the content of the introduction.

Goal: The goal of this section is to give students a format in which to discuss their results by separating the discussion section into sub-sections using the same content strategy as the Introduction section but in reverse. Students will learn how to discuss: 1) the "smaller picture", to state if the results of the experiments support or refute the original hypothesis, 2) "the medium picture" to discuss the results of the experiments in relation to the journal articles cited, 3) any future experiments that can be conducted or experimental errors that may have occurred and, 4) "the big picture", how the results of the experiments impact what is known about the topic.

Student Learning: After using this worksheet, students will have the tools necessary to generate a discussion section that will utilize the data acquired and the information from references cited to make conclusions about the experiments performed. In addition, they will better understand how to format the discussion section effectively to walk the reader through their original hypothesis, how the results supported or refuted this hypothesis and how that fits in with information already published in relation to their research.

Current Implementation

This directed writing module was implemented at Georgia Gwinnett College (GGC), a 4 -year Liberal Arts College in the University System of Georgia that is an open-access college with non-competitive admissions. GGC has adopted a model of student-centered learning where there is an emphasis on active learning and small class sizes. Currently, both lower-division and upper division biology courses are capped at twenty-four students highlighting one important aspect of the student-centered model implemented at GGC. This set of scientific writing modules was designed for a sophomore-level Cell Biology laboratory, where the students have been separated into groups of four. For the semester-long research project, each lab group is tasked with completing a research project and each student is tasked with writing up and submitting their research findings.

To ensure that students had time to complete each assignment, receive feedback, and revise their original writing based on instructor feedback, the series of assignments described below were assigned sequentially throughout the semester. To maximize student learning, we set up the assignment sequence so that students could receive feedback on one section before moving on to the next segment. In this way, students would have time to process the comments and incorporate any necessary changes before being tasked with another section to complete. Table 1 is a proposed timeline for a standard 15 week fall or spring semester that could be implemented in a variety of laboratory settings. This process and timeline allowed students more time to reflect upon and refine their assignment based on the feedback before the final submission of the research article.

Table 1. Implementation timeline in a semester.

Week	Assignment	Feedback
2	Journal Article Identification Worksheet	Was there proper reference formatting?
4	Introduction Section	Were peer-reviewed publications used with proper citations, and a hypothesis formulated?
5	Methods Section	Were there thorough yet succinct descriptions of protocols used?
6	Results Section	Were tables and figures correctly formatted and a narrative results section included?
7	Discussion Section	Did the student evaluate the data in relation to previously published work?
10	Final Submission	Submit for a grade after reflecting on feedback given.

Feedback from each section is detailed but can come in multiple formats. In the current implementation, faculty members have provided feedback using rubrics and written comments. Faculty responses also note issues with the scientific writing style, in-text citations, and the use of valid sources. Students are expected to make the suggested changes before submitting the final document.

Week 2

Lab Worksheet: Journal Article Identification Worksheet

To obtain journal articles/peer reviewed publications for scientific lab report writing, you can use the following sources:

- PubMed Journal Database http://www.ncbi.nlm.nih.gov/pubmed
- Google Scholar http://www.scholar.google.com
- Your institutions library website and interlibrary loan

Search terms matter. Make sure you think hard about what you are searching for and include terms that refine the search. For example, if your research project involves the effect of a lemon juice on the growth of mammalian cells, important search terms would include; lemon juice & mammalian cells & cell growth.

Identify the journal article that supports your individual lab report. This must be a complete article and not just an abstract. Make sure you understand what a **peer reviewed publication** is when choosing, the difference between peer-reviewed publications and other information found on the internet is integral when putting together a scientific laboratory report.

Journal Article Identification and Citation Formatting

Use the journal article chosen to answer the following questions.

List the names of the authors in order.

What is the year of publication?

What is the title of the article?

What is the name of the journal?

What is the volume number (if any)?

What is the issue number (if any)?

What are the pages assigned to this article?

Reference Page Format

Based on the above information and using the example below, write your APA formatted citation for this journal article. This would be what is found in the bibliography section if you cite this article in your report.

Author, A. A., Author, B. B., & Author, C. C. (Year). Title of article. *Title of Periodical*, volume number (issue number), pages.

In-Text Citations

Based on the above information and using the examples below, write your APA formatted in-text citation for this journal article. In-text citations are used when stating information from a source, usually in the introduction or discussions sections. You must determine if your journal article has only 1-2 authors… or if it has 3 or more authors. And then cite your journal article both within a sentence or at the end of a sentence as demonstrated below.

If 1-2 authors, then both names listed in all formats:
Example if cited within a sentence: Research by Smith and Johnson (2007) supports...
Example if cited at the end of a sentence: (Smith & Johnson, 2007)

If 3 or more authors, then all author names are listed for the first citation of the paper:
Example if cited within a sentence: Not possible to do until after you cite once at the end of the sentence correctly. Too many names listed at the start of a sentence is distracting to the reader. Avoid whenever possible.
Example if cited at the end of a sentence: (Alvarado, Baker, Huang, Schmidt, & Jackson, 2003)

Write an example of your chosen journal article cited within a sentence:

Write an example of your chosen journal article cited at the end of a sentence:

In-Text Citations – Using the Latin Phrase et al:

If you have under 2 authors, then the answers in the above question are your only option on how to cite within your lab report. If your article had 3 or more authors, then once you cite your article for the first time (as demonstrated in the previous question), then every other time you can change to the following format:

If 3 or more authors only:
Example if cited within a sentence: According to Alvardo, et al (2003) …..
Example if cited at the end of a sentence: (Alvarado, et al., 2003)

Write an example of your chosen article cited within a sentence using et. al:

Write an example of your article cited at the end of a sentence using et. al:

Week 4

Lab Worksheet: Introduction Section

The Introduction section provides the reader with the background information necessary to understand the reasons for the experiment within. To write this section professionally, then it must be **written in third person**.

Introductions are broken into three main sections.

The **FOUR paragraphs** needed for this section lab report are identified below:

The first section of the Introduction section of the lab report is termed the "**big picture**". This is the overview topic of the research conducted.

Paragraph 1: Discuss the big picture of your experimental design.

The second section of the lab report is termed the "**medium picture**". This is continued background information but more specific to the experiment itself.

Paragraph 2: Discuss the general results of your ***first*** journal article. Make sure to include the population studied. Must include formatted in-text citations. For example, "According to Behr and Jenkins (2004), 25% of the 50 rats studied died after digesting 2mg/ml of lemon juice for 2 months. This study also demonstrated….".

Paragraph 3: Discuss the general results of your **second** journal article as described above (for paragraph 2).

Additional paragraphs are permissible if more than two journal articles will be discussed.

The final section of the Introduction section of the lab report is termed the **smaller picture**. This is where your state your specific hypothesis statements and prediction for the experiment. Be direct. The Reader should not have to guess what you mean. **Do not** discuss any of the methods, nor discuss any research/ journal article in this section.

Paragraph 4: This section should include a direct and clear statement of hypothesis and prediction. Please use the words "hypothesis" and "prediction" within the paragraph to be clear

Remember:
The subheading "**Introduction**" is required.
This section must be sentences/paragraphs only. Do not include bullet points.
Indent each of your paragraphs.
No quotes are allowed in any part of scientific writing.
Include all **citations** within the text and a **reference list** at the end of the section as described in the Journal Identification Worksheet.
If you want to use an abbreviation, then you must define that abbreviation the first time you use it.

Week 5

Lab Worksheet: Methods Section

The Methods section describes what experimental process was done to achieve the results. To write this section professionally, then it must be written in the past tense, third person and be **BRIEF**.

Examples of irrelevant and relevant items below:

DO NOT STATE - IRRELEVANT	**DO STATE - RELEVANT**
The cell pellet was mixed/titrated 20 times.	The cell pellet was re-suspended.
The supernatant was removed slowly to prevent disturbing the cell pellet.	The supernatant was removed and the cell pellet was resuspended in XXmls of XX solution.
Phalloidin (600ul) was added to the wells. After 20 minutes 600ul was removed and 600ul of PBS was added. This was incubated for 3 minutes. Then that 600ul was removed and 600ul of PBS was added again…. etc.	Cells were stained with X concentration of phalloidin for XX minutes; and then washed three times.
GENERAL ITEMS TO NOT STATE	**GENERAL ITEMS TO STATE**
The media was warmed for 5 minutes.	The speed and time for centrifugation.
Items were placed in the trash/waste beaker.	The procedure was repeated twice (if this applies to you).
A new pipette tip was used every time.	The time, temperature and location that cells were incubated.
Tubes were labeled or gloves were used	The name and concentration of all solutions as you use them in the experiment.
Lids/caps were removed to pipette.	The proper name for all equipment.
The flasks were swirled.	To stop the trypsin reaction, Xmls of media were added to the flask.

Remember:
The subheading **Methods** is required.
Writing must be sentences/paragraphs only. Do not include bullet points.
Protocol must include enough information for another person to complete your experiment.
If you want to use an abbreviation, then you must define that abbreviation the first time you use it (such as PBS).
The **exception** to this is units like mg, µg, °C, etc.… no need to define units prior to using.

Week 6

Lab Worksheet: Results Section

The Results section describes the data collected and the mathematical analysis of that data. It does not describe what the results mean, **so no interpretation of the data is included in this section**. To write this section professionally, then it must be written without personal pronouns and be **BRIEF**.

Results section is in two parts, the graphical part and the narrative part:

Narrative Part

This section is the results section in written form. This section needs to be a complete picture of your experimental results. It is independent of the graphical section. This means that a reader should be able to read the Results written section and know all of the results, without viewing the graphical section. For each paragraph: 1) A lead in sentence to the paragraph, 2) Explain the results obtained and 3) Close out the paragraph with a sentence. Descriptions of data trends are acceptable; however, do not interpret the data, just state the results.

Example of a description of a data trend (**OK** to put in Results Section): "The cells treated with lemon juice had twice as many viable cells as the control."

Example of data analysis (**NOT OK** to put in Results Section): "Lemon juice causes mammalian cells to grow."

Graphical Part:

This section should include the following properly formatted tables and figures.

Remember:
The subheading **Results** is required.
Writing must be sentences/paragraphs only. Do not include bullet points.

Formatting Tables and Figures

Formatting Tables:

What Is in a Title?

The title of a table consists of 3 things:
Identifier – such as "Table 1"
Punctuation – either a colon ":" or period "."
Descriptive title – title must be interesting, but direct about the contents within the table.

How Do You Format a Title?

Title must be ABOVE the table (no spaces between)
Title must be in **bold**
Title must not exceed one line
Title must fit the width of the table

Suggestion:
Use a textbox for the title in order to easily meet expectations.
Is there anything else needed besides the title (as explained above?): No.

Example Table Provided:

Table 1. Analysis of the effects of lemon juice on ptk2 rat-kangaroo cells.

	Cells NOT treated with Lemon Juice	**Cells treated with Lemon Juice**
Total concentration of cells	1.34×10^6 cells/ml	2.6×10^5 cells/ml
Concentration of viable cells	1.292×10^6 cells/ml	0 cells/ml
Concentration of nonviable cells	4.8×10^4 cells/ml	2.6×10^5 cells/ml

Formatting Figures

Creating Figures from Analysis of Cells Treated and Not Treated with Lemon Juice

Creating the graph(s) from the table in Part I is the next step. The figures are used to highlight the differences between the control and experimental groups. Because you are graphing a single data point, a bar graph or a pie graph is the best way to represent this analysis.

Remember:
For your lab report you will be using Microsoft Excel (or similar product) to create these figures, not by hand.

What Is in a Figure?

The title of a table consists of 3 things:
Identifier – such as "Figure 1"
Punctuation – either a colon ":" or period "."
Descriptive title – title must be interesting, but direct about the contents within the table.

How Do You Format a Figure?

Title must be BELOW the figure (no spaces between)
Title must be in **bold**
Title may exceed one line
Title must fit the width of the figure

Suggestion:
Use a textbox for the title in order to easily meet expectations. Consider formatting text using the Justify button.

Is There Anything Else Needed Besides the Title (As Explained Above?)

Yes! Additional sentences (approximately 2-3) are needed after the tile (**not in bold**).
Axis must be labeled

An Example of Student Results Generated from Their Chosen Research Question and Experimental Design

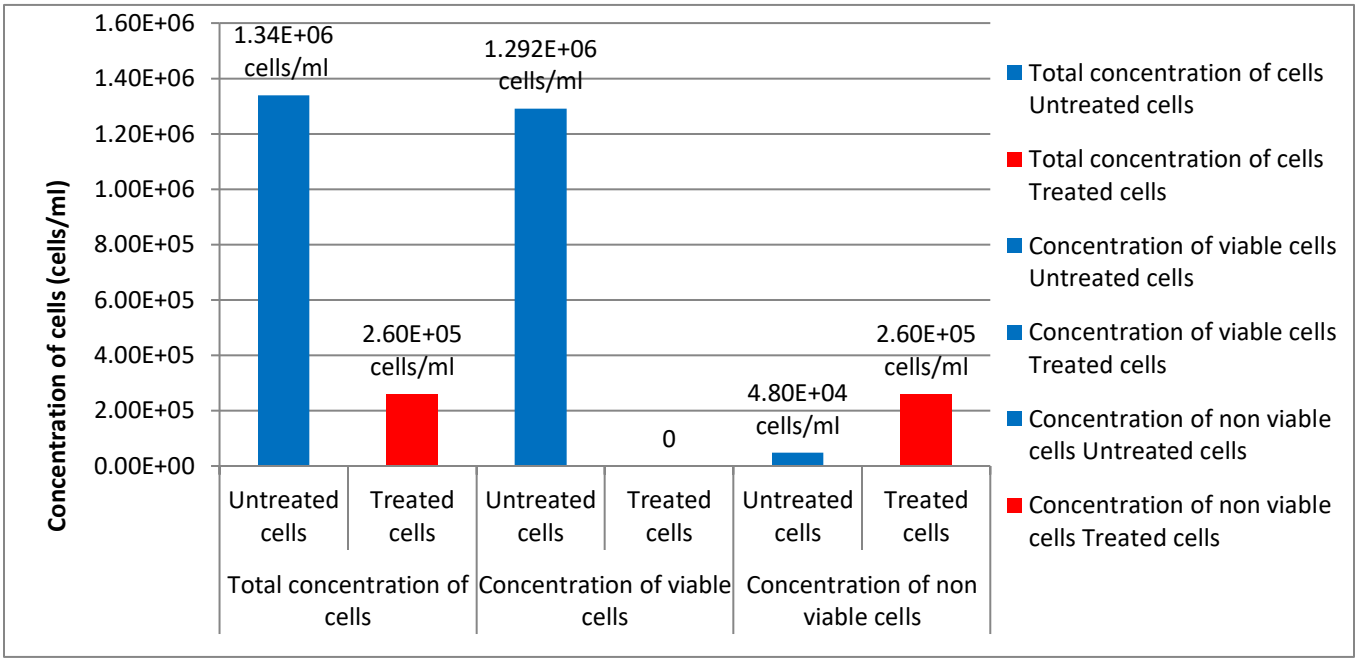

Figure 1. Total concentration, concentration of viable cells, and concentration of nonviable cells of lemon juice-treated and untreated cell populations. The cell population not treated with lemon juice had total cell concentration of 1.34 x 10^6 cells/ml, and the treated population had 2.60 x 10^5 cells/ml. The cell population untreated with lemon juice had total cell concentration that is 1.08 x 10^6 cells/ml greater than the treated population. No viable cell noted in the cell population treated with lemon juice, with 1.292 x 10^6 Cells/ml of viable cells in the untreated population. The treated cell population had 2.60 x 10^5 cells/ml of nonviable cells, and the untreated cell population had 4.80 x 10^4 cells/ml of nonviable cells. The cell population treated with lemon juice had 2.12 x 10^5 cells/ml greater nonviable cells than the cell population untreated with lemon juice.

Week 7

Lab Worksheet: Discussion Section

The Discussion section combines the meaning of the results with the content of the introduction. To write this section professionally, then it must be written in third person. Discussions are broken into similar sub-sections and follow the same content strategy as the Introduction section but in reverse. The Introduction discussed the bigger picture → smaller picture; while the Discussion discusses the smaller picture → bigger picture.

The first section of the Discussion section of the lab report is termed the "**smaller picture**". This is about the hypothesis/prediction.

Paragraph 1: Clearly and directly state if the results of these experiments support or refute the hypothesis and explain why. It is always possible that you might have two varying results. In this case, you would need to discuss they hypothesis being supported or refuted for each experiment individually. Don't forget to explain why.

The second section of the Discussion section of the lab report is termed the "**medium picture**". This is a discussion of your results and what they mean for the provided information. This section must include formatted in-text citations.

Paragraph 2: Discuss how the results of the experiment support or refute the information from the ***first*** journal article and explain why. You may have to discuss each experiment separately if your experiments obtained conflicting results for the two experiments.

Paragraph 3: Discuss how the results of the experiment support or refute the information from the ***second*** journal article and explain why, as described above (for paragraph 2).

Additional paragraphs possible if more than two journal articles will be discussed.

Paragraph 4: Based on the above, discuss any **future experiments that** can be conducted to continue the current research you started. Also, discuss any **experimental errors** that occurred in the lab setting that may explain why your results are different from the previous research.

The last section of the Discussion section of the lab report is termed the "**big picture**". This ties into the first paragraph of your Introduction section to close out the lab report.

Paragraph 5: Discuss the big picture and how the results of the impact what is known about this topic. And include closing statements to end the paper. If using common sense information, then no in-text citations are required.

Remember:

The subheading "**Discussion**" is required.
This section must be sentences/paragraphs only. Do not include bullet points.
Indent each of your paragraphs.
No quotes are allowed in any part of scientific writing.
Include all **citations** within the text and a **reference list** at the end of the section as described in the Journal Identification Worksheet.
If you want to use an abbreviation, then you must define that abbreviation the first time you use it.

Materials

Materials needed vary depending upon implementation. Currently the lab manual is posted on the course learning management system for students to review and/or print necessary pages. This module has also been added to the course lab manual as an appendix. No monetary costs to faculty were incurred using these implementations.

Notes for the Instructor

The challenges faced in implementation of this writing module is the time needed by faculty members to provide timely feedback and still meet the goal of improving scientific literacy within the student population. Our school does not have the resources for teaching assistants, so the workload of this module is the responsibility of the faculty member teaching that lab section. Organization of the module was designed to address this issue. First, the disassembling of a scientific journal article into smaller, individual parts allowed faculty members to grade approximately 2-4 paragraphs per writing assignment. This allowed for a shortened grading time even with the emphasis on detailed feedback. Second, the instructions were written in detail about the expectations of each paragraph. This allowed faculty members the flexibility to discuss this in lab or just post on the learning management system. Lastly, student expectations for the assignment were provided at the start of term and maintained by all faculty members. This provided faculty with a support system for difficult assessment decisions such as the penalty for students not implementing the suggested changes in the final article submission.

The design of the directed writing module is ideal for small class sizes, but since not all schools have the same format, we have included some suggested modifications to this module for different classrooms or courses. The key to this module is the detailed feedback and schools with larger class sizes may find written feedback for each section cumbersome. A suggested modification would be to generate a detailed, annotated rubric for use with this assignment. Instructors or teaching assistants using the rubric could assess a larger number of submissions in a shorter amount of time. Peer-review is also an option to decrease grading by faculty members. Students would be given copies of student work (without identifiers) and a rubric to grade the assignment. In lower level courses, it is not suggested to have a peer-review evaluation of the initial drafts because the students are still learning the format. Rather after the initial feedback, a second draft could be assigned and reviewed by their peers. Upper-level courses where students have been exposed to this writing module could introduce peer feedback in the first draft. To shorten the length of the module and number of submissions, it is also possible to group multiple sections into one assignment.

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