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Using the Writing and Revising of Journal Articles to Increase Science Literacy and Understanding in a Large Introductory Biology Laboratory Course

Daniel J. Treacy¹ and Melissa S. Kosinski-Collins^{2*}

¹Department of Biology, Massachusetts Institute of Technology, Cambridge, MA 02139. ²Department of Biology, Brandeis University, Waltham, MA 02454

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Abstract

Cientific literacy is directly correlated with building a new Ageneration of stronger scientific minds that can effectively communicate research science to the general public. Increasing communication skills in reading and writing scientific work should help improve student understanding in the areas studied. We have constructed an introductory laboratory in biology at Brandeis University that utilizes the writing and reading of scholarly articles to increase student understanding and scientific literacy. The written assignments of the course are designed to guide the students through the process of studying what is known, interpreting their own experimental data, forming unique and rational conclusions, and finally critiquing their work. We have found that students appreciate this method of learning and are better able to make the conceptual connections between real laboratory data and the concepts governing the experiments.

Key words: Science writing, introductory biology, science literacy, lab reports

Introduction

Improving scientific literacy has been linked to the development of a strong, socially aware citizenship and a stronger work force (National Academy Press, 2007; Rutherford and Ahlgern 1990). Communication and literacy are key factors in the promotion of future growth and continuation of research in all fields of science. This is especially true in the field of science education and for those responsible for fostering future scientists. Literacy and excitement of why science is performed and what can be gathered from the subsequent data is pivotal to the attraction, retention and support of a diverse generation of scientific thinkers (National Research Council, 2003).

Scientific literacy enables students to better understand research and the scientific method creating more knowledgeable citizens to take part in decision-making that may concern themselves or the greater community. Additionally, students who are scientifically literate should be able to critically judge and evaluate conclusions made about science and research in the general media (American Association for the Advancement of Science, 1993). In order to become a competent member of the global society and engage others in the process of critical thinking (not limited to the sciences), students must be able to communicate, read and write effectively (Krajcik and Sutherland, 2010).

Literacy is represented in many forms of communication within the scientific community as well as towards the greater populous. The forms most common to the field of science education include reading primary literature, oral presentation, and written assignments. Written assignments designed specifically to encourage a deeper level of understanding help to develop a greater amount of thinking on a higher order (Prain and Hand, 1999). These purposeful, writing assignments should encourage more higher-level thinking, defined by Bloom's taxonomy of learning domains as synthesis and evaluation, as opposed to most college-level science assessments which focus primarily only on lower-level cognitive skills (Bloom, 1956; Momsen et al., 2010). Using improved writing strategies in science courses have resulted in a number of beneficial outcomes. Some noteworthy examples include: increased performance on conceptual questions, a gained appreciation of the meaning of laboratory data, and an overall better understanding of information (Hohenshell and Hand, 2006; Keys et al., 1999; Rudd et al., 2001). In addition, the incorporation of scientific writing into inquiry-based curricula has been discussed as a means to increase student understanding and involvement in laboratory projects (Pearson et al., 2010). Writing exercises that are designed properly showing underlying connections between course topics can improve performance and help students understand complicated material (Miller et al., 2004).

Asking students to write real scientific articles based only on actual data and devoid of personal reflections has become increasingly difficult. In most language classes, students are taught to write in a manner that produces work that is story-like, and reads much like prose using "Six Plus One Writing Traits" methodologies (Stewart, 2010). Students tend to focus on the overall story presented in their reports rather than arguing conclusions based strictly on their results. Students also have difficulty speaking the specific academic language used in science that uses not only a distinct vocabulary but incorporates scientific word associations and inflections (Snow, 2010). Practice and proper feedback in assigned articles could potentially help students grow as science writers.

In some university-level, science writing assignments, students are asked to construct reports that discuss experiments with expected or known outcomes. Although these assignments allow students the opportunity to practice the language and vernacular used in science writing, they rarely provide a means to increase student comprehension of the topic. When there is only one expected outcome, as is the case for many introductory laboratory courses, students realize that all that is needed to succeed is simply restating or conforming to what the professor expects (Keys, 1999). In fact the students focus is on getting the "correct results" rather than on the scientific process or the significance of those results. In order to be truly effective as a method to increase students' comprehension of the subject matter, writing assignments should incorporate a certain quality of the unknown, giving rise to a greater understanding of how the scientific method actually works.

We have designed and incorporated a new series of science reading and writing assignments into the introductory biology laboratory course at Brandeis University. We assign journallike laboratory reports to students concerning the project-based, open-ended laboratory series and require our students to read primary literature. By using these assignments, we have provided them with an opportunity to increase their scientific literacy, understand conceptual connections between laboratories and allow students to practice better science-writing techniques. We feel our methodology of teaching science writing can help to better student understanding of research science and to produce a generation of active scientific thinkers. This method could potentially be used as a model for designing science writing assignments at other universities.

Methods

Writing Requirements in Introductory Biology at Brandeis University

Brandeis is a private, liberal-arts university in Waltham, Massachusetts with an entering first-year class of about 800 students. The university requires certain types of courses for graduation in addition to the courses required for the individual majors. These include a course in each of the schools of the university (science, social science, humanities, and fine arts), foreign language, as well as writing-intensive courses. Writing-intensive courses are defined as courses that "involve frequent writing assignments and opportunities for rewriting and consultations with the instructor" (Brandeis University).

About one quarter of the 800 students of each class take the introductory biology courses each semester as well as their accompanying laboratory courses. Biol18b and Biol18a are the introductory level biology laboratory courses that accompany the sophomore-level general biology lectures in cell biology and genetics, respectively. The laboratory courses are independent entities complete with their own weekly one hour twenty minute lecture and weekly four-hour laboratory session. The second semester of the lab (Biol18a) counts towards the university writing-intensive requirement. Because Biol18b and Biol18a are consecutive courses with similar lab reports, we will focus on the first semester (Biol18b) where students are initially exposed to our journal-like writing assignments.

Course Description of Biology 18b

Biol18b is a ten-week inquiry-based project laboratory that is divided into sections of twenty-four students each led by a graduate and undergraduate teaching assistant. During the laboratory, students work in pairs to design, purify and analyze a new mutant of humar VD crystallin, a protein implicated in cataractogenesis. During the laboratory, the students use site-directed mutagenesis to design and create their own mutant which they then over-express and purify from E. coli (Kosinski-Collins and King, 2003). The recombinant protein is analyzed using UV and fluorescence spectroscopy to determine its stability as compared to wild-type crystallin. Since the proteins produced are of the students' own design, the stability results are new to the scientific community and cannot be predicted before the completion of the project. In the second week of the semester, students are required to read and interpret a research article discussing crystallin. Additionally during the ten-week laboratory process, the students are asked to write two individual journal-style lab reports about their own personal experiments and results.

Assessment of Course Curriculum

Students were given the option to complete an anonymous, written evaluation at the beginning of the spring semester of the course (Biol18a) reflecting on their work in the previous semester (Biol18b). The questions focused mainly on gauging student interest in a project-based course format, but additionally questioned student perception and interest of the laboratory class structure including the incorporation of journal-style lab reports. Of the 176 students enrolled in the course, 138 completed the survey (78.5%). Students were asked to evaluate each question with a numerical score of one (least valuable) to seven (most valuable). Positive values are indicative of responses of 5 or higher on a scale of 1 to 7 for each question, respectively.

Assignments and Curricular Design

Reading Primary Literature

In the second week of the semesters students are required to read and discuss a published article on the topic of the semester's project, ∛D crystallin mutations (Nandrot et al., 2003). For most students, this is the first time they are exposed to reading primary literature articles. Students are required to read the article and come to class with answers to the pre-lab questions concerning it. These questions focus on different components of published articles and are listed in Table 1. The questions also serve as a guide for what type of information students should be able to gather from reading and for what guestions they should be asking while reading. Upon arriving to class, the pre-lab questions are discussed in small student-led groups after which the graduate teaching assistant leads each section as a whole through a discussion of both the pre-lab questions and other misconceptions which may have arisen while reading. This exercise familiarizes students with both the components and stylistic nature of a scientific research article such that they may then approach their own lab report assignments with knowledge of journal-style science writing.

Rubric-Based Grading

The lab reports, and the subsequent rewrites, account for a total of 40% of the final course grade (each report is 10%). The laboratories upon which the lab reports are assigned are changed each semester and from year to year to prevent in-

 Table 1. Pre-lab questions to help students' literacy when reading scientific articles.

What was the purpose of this experiment?
What was the hypothesis the authors were trying to test?
What techniques did the authors use to test their hypothesis?
What results dud the authors get from their experiments?
What conclusions did the authors make from these results?
What future experiments, if any, did the authors suggest should be performed in any subsequent studies?
Who were the authors of this paper? What was the presumptive role of each?
Where did the funding come for this research? To whom was it granted?

cidents of academic dishonesty, but the overall content and individualized components of the assignments are consistent. For example in the fall of 2008 the first of these reports encompassed the first three weekly labs (site-directed mutagenesis of a plasmid containing the CRYGD gene), while the second focused on the seventh week's lab session (humar \sqrt{D} crystallin protein growth and expression in *E. coli*). The students were asked to focus on and discuss only their own data collected during the lab itself. Because students were expressing their own proteins, each partner pair obtained their own unique results that could not be shared or predicted from data obtained by classmates or students from previous years. A majority of students felt that writing the full lab report helped to connect individual labs and concepts throughout the semester (Table 2).

Due to the class size, the lab reports are graded by section by different graduate students using a class-wide rubric (Appendix A). Rubric-based grading has been effectively used for promoting critical thinking in written assignments, making students aware of issues in their writing without giving specific ways to fix these issues (Oliver-Hoyo, 2003). To facilitate consistency between sections, the graduate students are trained in grading techniques by the course professor. The rubric assesses different components of the lab report on a scale of 0 (Unacceptable) to 4 (Above Standard) for a total of 112 points. The grades

 Table 2. Student responses to questions concerning the writing of lab reports.

	Percent of students responding to each value			
Question	Of little value (Scores 1-3)	Of moderate value (Score 4)	Of high value (Scores 5-7)	
How useful were lab reports in understanding the purpose of your experiment?	11	5	84	
To what extent did writing a discussion section help you interpret and understand your data?	7	15	78	
How useful was writing your lab report in learning how to find appropriate primary literature?	30	16	54	
How useful was the primary literature in understanding your experiment?	48	17	35	
How useful was writing a full lab report in connecting individual labs through the semester?	15	15	70	
How useful was the rubric as a guideline to write your work?	17	11	73	
How useful were the rewrites in (better) understanding your experimental purpose	16	12	73	
How useful were the rewrites in leaning to critique your own work?	9	14	80	
How useful were the rewrites in learning to write concisely?	15	11	76	
How useful was the rewrite in helping you distinguish between sections of a lab report?	13	15	73	
How useful was the feedback (rubric scores and comments) from the first draft in doing the rewrite?	25	14	62	

were then determined by utilization of a standard bell curve scale centered at a B. Survey results revealed that most students found the rubric to be very helpful as a guideline to write their reports (Table 2).

Components of the Biol18 Lab Report

The journal-style lab report consists of seven distinct sections: title page, abstract, introduction, methods, results, discussion and references. As explained by the course professor, each of these sections with the exception of the references should be able to provide the reader with enough information so he or she understands the experiment without having to read the entire report. Each section has different requirements and the rationales behind writing them are outlined below. A detailed version of the writing guidelines is given in Appendix B.

The abstract, similar to any academic abstract, is a oneparagraph summary of the experiment and the most important part of the manuscript. Each abstract should contain some introductory information, the experimental purpose, a brief description of what was done, the main points obtained from the data, what was learned from the experiment, and finally what would be done as a follow-up study. Students were graded on each of these sections for completeness, clarity and conciseness. In addition, students were strongly discouraged from presenting any raw data obtained and only to present the main points, both gathered and inferred, of their experiment(s).

The introduction needs to provide the reader enough information to understand the basics and background behind the experiment. Students did not seem to grasp this concept as observed in survey results. Only about half of students reported some positive value to the usefulness of writing the lab report in finding appropriate primary literature. About the same percentage of students reported a negative value to the usefulness of the primary literature in understanding the experiment performed (Table 2). These results indicated that further explanation on how to utilize and understand research articles is needed. The introduction also serves to reintroduce the project performed: the experimental purpose and what was found. Students felt very strongly that writing these reports helped them understand the purpose of their experiments as 85% of students reported a positive value to this component of the reports. In contrast to the abstract, where the data presented is quantitative, students are strongly encouraged to present data only in a qualitative form.

In the materials and methods section, students are highly encouraged to be as concise as possible while providing all of the needed information to perform the experiment. Examples of descriptions of protocols published in journals such as <u>Protein Science</u> are provided to help students understand the exact nature of the brevity used in science writing. Specific changes from what is written in the lab manual to what is actually performed in the laboratory have been made clear to students and implemented in order to observe that they were actually taking notes during their lab experiments. For example, instead of writing statements such as "Plates were incubated for 1-2 days at 37° C" students are asked to write "Plates were incubated for 26 hours at 37° C."

The results section is designed to provide students a clear distinction between what is a result and what can be inferred from that result (conclusions). Each set of data should be in context of the experiment performed, with a brief introduction about the how and why, as well as having an appropriate amount of proper labeling for the data. A person reading this section should be able to understand the same message by reading either the written, objective analysis or the data in the graphs and figures. The professor emphasizes this need for presenting the same data in both text and in figures during class discussions. Conclusions and interpretations of the data are described in the discussion. Students felt very positively that discussion sections helped them to interpret, and more importantly, understand their data as 78% reported this to be of high value (Table 2). Students are required to draw conclusions from and support these claims with their own data as well as being strongly discouraged from making claims that extend beyond the scope of the experiment.

Rewrite Process

Once an initial lab report is submitted, the teaching assistant in charge of grading has one week to grade and make comments on each report for the section of twenty-four. During the next week's lab sessions students receive their lab reports back with comments from the teaching assistant and what can be gathered from the rubric scores. The students then have one week to look over the commentary and rewrite their lab reports in order to address the issues brought up in the first draft. Students are encouraged to meet with either their TA or the course professor to discuss any corrections or misunderstandings in commentary during this time. The rewrites are then graded with the same criteria as before with special notice taken to what changes have been made to the reports.

The majority of students (62%) found the feedback, rubric and written, from the rewrites to be at least somewhat valuable. Eighty percent of students found the rewrite process to be of high value in learning how to critique their own work. Additionally, about three quarters of the students surveyed felt that the rewrites were valuable to learning how to write concisely, which is one of the key writing goals set out for this course.

Conclusions

Most students enter the introductory biology labs without having read a published, scientific article or written an article that was publishable. Therefore, students have not been required to truly think about the relevancy of a scientific study and may not fully appreciate the work done. In order to avoid this and instead promote student learning and understanding of research science, we have implemented a writing-intensive, introductory laboratory in order to promote scientific literacy and inquiry. Over the course of two semesters, students taking the introductory labs, Biol18b/a, at Brandeis perform weekly experiments and must then interpret and gather conclusions from their own experiments. The process of writing a lab report for these courses includes multiple rounds consisting of writing a graded first draft, receiving edits and comments back in order to help critique their work, and finally rewriting and submitting a finalized report. Reports are written as if for publication to promote understanding of science as a process and to emphasize the importance of speaking "the language of science". Students responded well to this process with the exception of writing an introduction. We believe students did not understand the true value of using research articles to understand the questions and information covered in their experiments, especially since students were not designing subsequent experiments.

Writing assignments can, and should, be used as tools in all fields of science. These assignments would not simply function as additional evaluative processes but would actually better the scientists in our students (National Research Council 2003). Writing has been shown to increase scientific literacy and thus make students better ambassadors and teachers to people outside of the scientific community. Requiring that students write as if they were writing for a scientific journal creates certain knowledge of how to read and write in academic publications, a skill that is often not achieved until graduate school. This also forces students to think about the data that results from their experiments and what the data actually means, creating a better understanding of the basic science ideals supporting that data.

Giving students any assignment or situation that requires extensive time of thought should contribute to a better understanding of the subject matter and a higher level of cognitive thinking. Students should not consider writing assignments simply as a process of attaining a particular word count, but of attaining a greater level of reasoning and knowledge. This is especially true for inquiry and literacy-stimulating writing in the sciences. We have found that requiring students to read research articles and then produce journal-like research-level lab reports based on data collected from our project-based labs has increased the conceptual connections made by our students. We feel our approach to reading and writing in introductory biology could be used at other institutions as a model for increasing understanding and scientific literacy. At institutions where the teaching resources are more limited, the complete lab report can also be broken into multiple writing assignments through the semester.

References

 American Association for the Advancement of Science (1993) Benchmarks for scientific literacy. New York: Oxford University Press.
 Bloom B. S. (1956). Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain. New York: David McKay Co Inc.

- Brandeis University (September 2010) University Writing. Brandeis University Bulletin (2010 2011). http://www.brandeis.edu/registrar/ bulletin/provisional/req-ugen/wi.html.
- Committee on Science, Engineering, and Public Policy, Rising Above the Gathering Storm (2007) Energizing and Employing America for a Brighter Economic Future (National Academies Press, Washington, DC.
- Hohenshell LM, and B Hand (2006) Writing-to-learn strategies in secondary school cell biology: a mixed method study. International Journal of Science Education 28: 261–289.
- Keys, C. W. (1999). Revitalizing instruction in scientific genres: Connecting knowledge production with writing to learn in science. Science Education 83: 115-130.
- Keys, C. W., Hand, B., Prain, V., & Collins, S. (1999). Using the science writing heuristic as
- a tool for learning from laboratory investigations in secondary science. Journal of Research in Science Teaching 36: 1065-1084.
- Kosinski-Collins, M.S.& King, J.A. (2003). In vitro unfolding, refolding, and polymerization of human D crystallin, a protein involved in cataract formation. Protein Science 12: 480-90.
- Krajcik, J.S. and Sutherland L.M. (2010) Supporting students in developing scientific literacy. Science 328: 456-459.
- Miller, R. G, Calfee, R. C. (2004) Making Thinking Visible. science.nsta. org/enewsletter/2005-11/sc0411_20.pdf
- Momsen, J. L., Long, T. M., Wyse, S. A., & Ebert-May, D. (2010) Just the facts? Introductory undergraduate biology courses focus on lowlevel cognitive skills. CBE Life Science Education 9: 435-440.
- Nandrot, E., Slingsby, C., Basak, A., Cherif-Chefchaouni, M., Benazzouz, B., Hajaji, Y., Boutayeb, S., Gribouval, O., Arbogast, L., Berraho, A., Abitbol, M., and Hilal, L. (2003) Gamma-D crystallin gene (CRYGD) mutation causes autosomal dominant congenital cerulean cataracts. Journal of Medical Genetics 40:262-267.
- National Research Council (2003). Bio 2010, Transforming Undergraduate Education for Future Research Biologists. Washington, DC: National Academies Press.
- Oliver-Hoyo, M.T. (2003) Designing a written assignment to promote the use of critical thinking skills in an introductory chemistry course. Journal of Chemical Education 80: 899-903.
- Pearson, P. D., Moje, E. and Greenleaf, C. (2010) Literacy and Science: Each in the service of the other. Science 328: 459-463.
- Prain, V. and Hand, B. (1999) Student perceptions of writing for learning in secondary school science. Science Education 83:151–162.
- Rudd, J. A., Greenbowe, T. J., Hand, B. M., and Legg, M. J. Using the science writing heuristic to move toward an inquiry-based laboratory curriculum: an example from physical equilibrium. Journal of Chemical Education 78: 1680-1686.
- Rutherford, F. J., Ahlgren, A. (1990) Science for all Americans. Oxford University Press, New York.
- Stewart, M. (2010) Science Education: Flouting Formality. Science 329: 724.

Student Name:

Score____/112

CONSTRUCTION	4 - Above Standard	3 — At Standard	2 – Approaching Standard	1 – Below Standard	0-Unacceptable
I. Writing Style					
A. Appearance/ Organization	Entire lab report is typed and uses	Entire lab report is typed and uses	Entire lab report is typed, but formatting	Lab report has handwritten parts and	Entirely
Ciguinzanon	to visually organize the material. Page	subheadings to visually organize the	material. Page breaks occur in	inappropriate places within sections.	reports.
	breaks are appropriate. Figures and	material. Page breaks are somewhat	inappropriate places within sections.	Figures and tables span multiple page	reportsi
	tables do not span multiple pages.	appropriate. Figures and tables do not	Figures and tables do not span multiple		
		span multiple pages.	pages.		
B. Report Format	All required sections are present and no	All required sections are present. One	One required element is missing. All	More than one required element is	Several sections
	components follow the set length	the report. All components follow the set	sections rollow the set length guidelines.	length quidelines	incomplete
	guidelines.	length guidelines.			
C. Data and calculations	Professional looking, digital, accurate	Accurate representation of the data in	Accurate representation of the data in	Accurate representation of the data in	No data
	representation of the data in tables	digital tables and/or graphs. Graphs	digital tables and/or graphs.	written form or data is handwritten.	presented.
	and/or graphs. Graphs and tables have	and tables have captions and are titled.			
D. Grammar, Spelling, and	Writer makes no errors in grammar.	Writer makes 1-2 errors in arammar.	Writer makes 3-4 errors in arammar.	Writer makes more than 4 errors in	More than 10
scientific convention	spelling, or scientific convention that	spelling, or scientific convention that	spelling, or scientific convention that	grammar, spelling, or scientific convention	typographical
	distract the reader from the content.	distract the reader from the content.	distract the reader from the content.	that distract the reader from the content.	errors in report
E. Flow & Rhythm (Sentence	All sentences sound natural and are easy-	Almost all sentences sound natural and	Most sentences sound natural and are	The sentences are difficult to read aloud	
Fluency)	on-the-ear when read aloud. Each	are easy-on-the-ear when read aloud,	easy-on-the-ear when read aloud, but	because they sound awkward, are	
	emphasis.	difficult to understand.	difficult to understand.	understand.	
SCIENTIFIC CONTENT	4 - Above Standard	3 – At Standard	2 – Approaching Standard	1 – Below Standard	0-Unacceptable
II. Title Page	Title professionally describes experiment	Title describes experiment in a complete	Title somewhat describes experiment. The	Title does not describe experiment. The	No collabor ators
	in a complete and active way. The author	way. The author and all collaborators	author and all collaborators are given.	author and all collaborators are given.	provided.
III. A hoten at	and all collaborators are given.	are given.			
A. Background	The background is clear concise and	The background is dear and directly	The background is clear, but not directly	The background unclear and not directly	Citations in
	directly related to the project.	related to the project, but not concise.	related to the project and not concise.	related to the project.	abstract.
		The wording is excessive and provides	The wording is excessive and provides		
		extraneous information.	extraneous information.		
B. Experimental Question	The purpose of the project is clearly	The purpose of the project is clearly	The purpose of the project is not clearly	\ I he reader cannot understand why the	No purpose is
ana memodology	understands why the project is being	clearly understands why the project is	project is being performed ΩR how ΩR	experimental question is OR how. Two	included.
	performed, how it is being performed	being performed and what the	what the experimental question is. One	ideas are missing or inaccurate.	
	and what the experimental question is.	experimental question is, but the wording	idea is missing or inaccurate.	, i i i i i i i i i i i i i i i i i i i	
		is excessive and provides extraneous			
C. Rosults	Ougntitative consists and complete	Information.	Quantitative and complete summary of	Incomplete er raw data ir included in	No summary of
C. Results	summary of results is given. No raw data	results is given. No raw data is included	results is given. No raw data is included.	results.	results is
	is included and results are distinct from	and results are distinct from discussion	Discussion ideas are incorporated with		include d.
	discussion points.	points.	results.		
D. Conclusion	The conclusion is briefly stated and	The conclusion compares the results back	The conclusion compares the results back	The student has not come to a sensible	No conclusions
	compares the results back to the purpose	to the purpose in a complete and	to the purpose in an understandable	conclusion based on the results. The	are given.
	in a complete and understandable way.	undersidhadde way, but is too long.	is missing or inaccurate.	hypothesis.	
E. Future Experiments	The future experiments are reasonable	The future experiments are somewhat	The future experiments are not	The future experiments are not directly	
	and directly related to the initial	reasonable and directly related to the	reasonable, but are directly related to	related to the initial experiment.	
IV Introduction	experiment.	initial experiment.	the initial experiment.		
A. Background Sources	At least three reputable background	At least three reputable background	A few reputable backaround sources are	A few backaround sources are used and	Material is
	sources were used and cited correctly.	sources were used and cited correctly.	used and cited correctly. Material is	cited correctly, but some are not	directly copied
	Information is directly related to project	Information is somewhat related to	translated into student's own words.	reputable sources. Material is translated	rather than put
	scope and result. Material is translated	project scope and result. Material is		into student's own words.	into students own
B. Experimental Purpose	The purpose of the project is clearly	The purpose of the project is dearly	The purpose of the project is not clearly	The purpose of the does not discuss the	No purpose is
	stated and concise. The reader clearly	stated and but is not concise. The reader	stated. The reader understands how OR	how or the why of the experiment.	included.
	understands why and how the project is	clearly understands why and how the	why the project is being performed. One		
	being performed.	project is being performed, but the	idea is missing or inaccurate.		
		wording is excessive and provides			
C. Summary of Results	Qualitative and complete summary of	Qualitative and complete summary of	Complete summary of results is given.	Incomplete summary of results is given	No summary of
	results is given in two sentences or less.	results is given.	. , ,	. , .	results is
L					included.
V. Materials and Methods	Due ee duuree and liste d'to survive a tot	Due en duran euro lla calda con al	Due en duran man liste d'ha a sur d'ar	Due en alvano processo de la colta de	Data an al survey in the
A. Proceaures	rioce aures are listed in appropriate	appropriate subbegdings but contain	appropriate subbeadings in the	r roceaures are not listed in the	included
	soone dulligs.	excessive wording. One additional	appropriate format. One necessary	unnecessary subheadings are included or	incloued.
	1	unnecessary subheading is included.	procedure is missing.	more than one necessary subheading is	
				missing.	
B. Formatting	format information under and	Procedures are listed in a somewhat	Procedures are listed in a somewhat	Frocedures are listed in an inappropriate	
	subheading is in complete sentences	each subheading is in complete sentences	appropriate formal.	rorman boller-point lists are used	
C. Protocol Changes	All changes to protocol are documented	All changes to protocol are documented.	Some changes to protocol are	No changes to protocol are documented.	
	and included in the appropriate format.	ļ	documented.		
VI. Results	Frank and a finder and the second			Mandata School II III	
A. Experimental Design	description of the experiment including	cach set of data is introduced by a description of the experiment including	some or aara is introduced by a brief	No aata is introduced by a brief	
	the why and how of the experiment.	the why and how of the experiment.	missing or incorrect why or how.	sessiplier of the experiment	
B. Data	Professional looking and accurate	Accurate representation of the data in	Accurate representation of the data in	Data are not shown or are inaccurate.	Data given
	representation of the data in tables	tables and/or graphs. Graphs and tables	written form, but no graphs or tables are		belongs to
	and/or graphs and in written form.	are labeled and titled.	presented.		someone else.
	titled.				
C. Calculations	All calculations are shown and the results	Calculations are shown and the results	Some calculations are shown and the	No calculations are shown OR results are	
	are correct and labeled appropriately.	are correct and labeled appropriately.	results labeled appropriately.	inaccurate or mislabeled	
	When applicable, calculations are				
D. Analysis	included in table descriptors.	The selecteration has seen to constant the	The selecteration has a set to constant the	The selectorship has not be used to be	
u. Anaiysis	An objective relationship between the variables is presented and	presented and trends/patterns logically	presented and trends/patterns logically	not presented	
	trends/pattems logically analyzed. No	analyzed. One discussion point is	analyzed. More than one discussion	no. prosenieu.	
	predictions or discussions of error are	included.	point is included.		
	included.	1	1	1	

VII. Discussion					
A. Data Analysis	The relationship between the variables is discussed and trends/pattemslogically analyzed in an aggregate manner. Predictions are made about what might happen if part of the lab were changed or how the experimental design could be changed. Reference is made to tables and figures containing appropriate data. Numerical values are given.	The relationship between the variables is discussed and trends/pattems logically analyzed. Predictions are made about what might happen if part of the lab were changed or how the experimental design could be changed. Reference is made to tables and figures containing appropriate data.	The relationship between the variables is discussed and trends/pattemslogically analyzed. Predictions are made about what might happen if part of the lab were changed or how the experimental design could be changed.	The relationship between the variables is discussed and trends/pattems analyzed. No predictions are made.	
B. Accuracy and Completion	All questions are answered accurately and completely. Discussion is in paragraph form in a cohesive and logical format.	All questions are answered. One question is answered incorrectly. Discussion is in paragraph form in a cohesive and logical format.	All questions are answered. More than one question is answered incorrectly. Discussion is in paragraph form in a cohesive and logical format.	All questions are answered.	Not all questions are answered.
C. Error Analysis	Experimental errors, their possible effects, and ways to reduce errors are discussed. No human error is included.	Experimental errors and their possible effects are discussed.	Experimental errors are mentioned.	There is no discussion of errors	
D. Conclusion	Conclusion includes whether the findings supported the hypothesis, possible sources of error, and what was learned from the experiment. Conclusions stay within scope of the experiment.	Conclusion includes whether the findings supported the hypothesis and what was learned from the experiment.	Conclusion includes what was learned from the experiment.	No conclusion was included in the report OR shows little effort and reflection.	
E. Summary	Summary describes the information obtained and some future applications or experiments.	Summary describes the information obtained.	Summary describes future experiments.	No summary is written	
VIII. References					
A. Formatting	All references are appropriately cited using the guidelines set in the lab manual.	1 mistake in punctuation or font is made in the references.	2 mistakes in punctuation or font are made in references	More than two mistakes in punctuation or font are made in references	No reference section is given
B. Types of references	A sufficient number of outside references of the appropriate types are provided. A citation for the lab manual is given.	A sufficient number of outside references of the appropriate types are provided, but the author is missing 1 source from primary literature. A citation for the lab manual is given.	An insufficient number of outside references of the appropriate types are provided. A citation for the lab manual is given.	No lab manual citation is given.	No reference section is given

Appendix B Writing an Abstract for Biology 18

Background

Every journal article has an abstract at the beginning to let the reader know what is in the paper. Abstracts are also printed in reference books or on PubMed to be used as guides as to whether or not reading the rest of the article is needed.

An abstract is a single paragraph summary of your experiment. Like a lab report it should contain an introduction, methods, results, and conclusions. The abstract should be short (no more than 300 words) and should tell the whole story of your experiment. The abstract should not rely on outside sources for details or additional information.

Parts of An Abstract

I. Title

II. Author(s) and address for where the experiments were performed.

III. Experimental/scientific purpose including who, what, where and why of the experiment.

IV. Results: State only your main point(s) and do not include any raw data.

V. Conclusions: What did your results tell you?

VI. Future Experiments: Write one sentence that tells of an experiment that should be performed to follow-up on this study.

Writing an Introduction for Biology 18

Background

The introduction defines the subject of the report. It puts the experiment in context and should explain:

• The background of the project (the related experiments that have come before it, the information on which the experiment depends); write as if writing for a Cell Biology or Genetics student not taking the lab. Note that the majority of the references, or notes, in a lab report will pertain to this early section of the paper

• The purpose of the project: its relation to the background; why it is being undertaken; or what hypothesis you were trying to test.

• A brief summary statement of the results. Do not include numerical values of results, just a qualitative summary.

Guidelines for Writing An Introduction

• Please limit your introduction to one page single-spaced.

• Please include at least 4 outside scientific references in addition to the manual. Three of your outside references must be from scientific journals (aka primary literature articles).

• Use the appropriate tense. Anything that has been previously published should be in the present tense as it is widely accepted scientific information. Anything describing what you did should be in the past tense. You did it previously and it has yet to be published.

Writing a Materials and Methods for Biology 18

Background

This section should contain a brief description of what was done. It is important to use the past tense for this section. A reader should be able to repeat your experiment by reading your materials and methods section, but may have to look up additional protocol details from documented sources. Be sure to include a reference to the manual as well as any changes to protocol that occurred while running the lab. Please write each aspect of the experiment as its own paragraph with the appropriate title and headings. Several examples of materials and methods from actual scientific journal are included below (Kosinski-Collins and King 2003).

Guidelines for writing a Materials and Methods 1. A previously documented protocol: Expression and purification of H/D-Crys

Recombinant human γ D crystallin was prepared from E. coli as described (Pande et al. 2000). Briefly, the protein was purified by fractionating cell lysate on a size exclusion column followed by cation-exchange chromatography as described (Broide et al. 1991).

2. A Newly Described Protocol: Equilibrium Refolding and Unfolding

For the unfolding equilibrium titration, purified $H\sqrt[9]{D-Crys}$ was diluted to 10 µg/mL in increasing amounts of GuHCl in S buffer from 0 to 5.5 M. S buffer contained 10 mM NaPO4, 5 mM DTT, and 1 mM EDTA, pH 7.0. The samples were incubated at 37° C until equilibrium was reached (6 h). For the refolding titration, 100 µg/mL protein was denatured in 5.5 M GuHCl in S buffer at 37° C for 5 h. The protein was subsequently refolded by dilution to 10 µg/mL into decreasing concentrations of GuHCl from 5.5 to 0.55 M. The fluorescence spectra of the equilibrated samples were determined using a Hitachi 4500 fluorimeter equipped with a continuous temperature-control system with excitation at 295 nm and emission from 310 to 420 nm. The emission intensities at 350 nm were used for data analysis. The excitation and emission slits were both set to 10 nm.

3. An Existing Protocol that has been Modified: Atomic Force Microscopy

Atomic force microscopy (AFM) analysis was performed using the tapping method as described (Marini et al. 2002). Ten µL of sample was allowed to nonspecifically bind to a mica surface for a total drying time of 75 sec. The mica was then washed with 150 µL of milli-Q water and allowed to air-dry before imaging.

It is up to you to determine how many experiments you need to describe and how to break down this protocol into different headings. Keep in mind, however, that each different procedure should have its own heading and paragraph description.

We will be looking very closely as to whether or not you have incorporated any changes to protocol in your materials and methods section. Specifically, there are certain protocol changes that we know occurred. We will be looking to see whether or not you documented these changes in your notebook and have written them into your materials and methods section.

Writing a Results for Biology 18

Background

The results section of a lab report includes any data you collected during an experiment. It often summarizes the data in photographs, tables, charts and graphs and rarely includes raw data except for in the case of photographs or direct observations. The results section includes data you collected, observed, measured, or calculated. The results section does not include anything you hypothesized, concluded, or speculated on after data collection.

Guidelines for Writing a Results Section

• Use the appropriate tense. The results section describes what you collected and did and, therefore should be in the past tense.

• All subtitled sections of the results should have a short introduction sentence describing in one or two sentences what you did to get the data that follows.

• All tables should have numbers, titles, and descriptors that describe any calculations that were used to obtain or calculate that data.

• All figures should have numbers, titles, and legends. The legend should describe all features observed in the figure whether appearing naturally or added computationally. If the figure was manipulated or edited in any way, the figure legend must include a brief description of what was done and what program was used to make the change.

• All results should be described in words. After each figure and/or table you must describe the experimental result found in it in written out sentences. You do not need to include a written description of control data.

• All calculations should be described in words as well as numbers. The calculation formulas may be included in table descriptors if applicable.

Writing a Discussion for Biology 18

Background

The discussion section includes any conclusions or interpretations you are making from your data. It includes speculations as to how things work and/or hypothesizes about what may have gone wrong. The discussion also includes any ideas the experiments may have inspired for possible follow-up experiments.

Guidelines for writing a discussion section

• Please limit your discussion to 1 page single-spaced.

• Use the appropriate tense. Reference to data often describes what you collected and did and, therefore should be in the past tense. Speculations in regards to the collected data should also be in the past tense. Future experiments should be described in the future tense.

- All discussion points should be supported with numerical data.
- All discussion points should refer to the appropriate figures and tables from the text.
- Any references to error in data collection and/or processing must be supported with actual numbers and relevant information.
- Conclusions found within the discussion section should be within the scope of the experiment.
- Discussions should not make conclusions beyond those that may be supported by the data collected during this lab.