Eliminating Lab Reports: A Rhetorical Approach for Teaching the Scientific Paper in Sophomore Organic Chemistry

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SINCE THE EARLY 2000S, many departments at Seattle University have adopted a "discourse approach" to outcomes assessment in which an instructor's report on the results of a course-embedded assignment leads to productive faculty discussion of student performance (Bean, Carrithers, and Earenfight 2005). Using this approach, a department typically identifies a senior-level assignment requiring "expert insider prose" (a term we have adopted from MacDonald 1994). The instructor grades the assignment using a rubric and identifies patterns of strength and weakness in students' work as preparation for a departmental discussion aimed at backward design of the curriculum. In that conversation faculty explore what might be done earlier in the curriculum, such as better instruction or improved assignment design or sequencing, to help novices improve their skills of disciplinary writing and thinking. This paper reports the results of this approach in the Department of Chemistry at Seattle University.

The Problems with Senior Theses in Chemistry

The Seattle University Chemistry Department embeds expert insider prose in a senior capstone project in which seniors report their own novel scientific research in three different genres: a scientific poster, an oral presentation, and a written senior thesis. Although the department assigns lab reports and other writing assignments in chemistry courses throughout the four-year curriculum, the senior theses are often disappointing. Over the last several years these capstone projects have exhibited the following kinds of problems: lack of a clearly stated scientific aim; inadequate background, theory, and context; illogical or unpersuasive presentation of data; uncertain target audience; poor organization; and non-professional style and/or format.

The chemistry department has been puzzled by these problems. Some faculty members hypothesize that students are simply poor writers, or they blame first-year composition for not teaching students how to write. Others think the problem arises from inadequate instruction in technical writing or from students' inability to transfer learning from one context to another. But until recently the chemistry faculty has not had a robust intellectual framework to explain weaknesses exhibited in senior theses and to allow progress toward sensible solutions.

Discovery of a Theoretical Framework

A conceptual breakthrough occurred when chemists Alaimo and Langenhan began conversations with WAC/WID specialists Bean and Nichols, who introduced them to recent work in genre theory by Bawarshi (2003), Carter (2007), and Beaufort (2007). Explaining the socializing function of genres, these theorists persuasively link disciplinary writing to disciplinary thinking and doing. Alaimo and Langenhan realized that students who do not write like professional chemists do not think like professional chemists. In a memorable lunch discussion of genre among the four co-authors of this paper, Bean and Nichols identified the traditional "term paper" as a pseudo-academic or school genre. ("Real scholars don't write term papers," they said.) Alaimo and Langenhan applied the same concept to the "lab report"; it too was a pseudo-academic or school genre. Real scientists don't write lab reports, or at least not the type that students write. Alaimo and Langenhan were particularly influenced by the following quotation from Carter: "WID developed as a response to the recognition that different disciplines are characterized by distinct ways of writing and knowing. Thus, a specialized conception of disciplinary knowledge is integrated with a specialized conception of writing" (387). They hypothesized that learning to write a scientific paper in the style of a professional chemist might initiate students into "a specialized conception of disciplinary knowledge."

These insights were further crystallized by Anne Beaufort's discussion of discourse communities, particularly by her Venn diagram of the skills/knowledge that students need in order to write expert insider prose in a discipline. In Beaufort's diagram, a large circle labeled "discourse community knowledge" contains four smaller overlapping circles: "subject matter knowledge," "genre knowledge," "rhetorical knowledge," and "writing process knowledge" (19). Beaufort's diagram illuminates the weaknesses of the lab report. Although writing a lab report ostensibly teaches "genre knowledge"—in that it typically follows the format of the standard scientific report—it does so only superficially: It treats genre merely as format identified by headings and sections. It is not a robust genre that initiates students into discourse community knowledge by engaging the full range of skills/knowledge identified in Beaufort's diagram. It fails to draw on subject matter knowledge (the typical cookbook procedures of many chemistry labs invite "plug and chug" thinking) or rhetorical knowledge (for example, the audience of a lab report is the teacher, not a professional community) or writing process knowledge (lab reports are generally written hurriedly with only superficial revision). Because a lab report typically does not address a genuine question, it does not teach students how scientists find questions, construct hypotheses, design experiments, or make arguments supported by data from the experiment. Overall, while the lab report provides a format for students to fill in as homework, it does not help students learn to think like a chemist.

So what might be an alternative to lab reports? Alaimo and Langenhan, as team teachers of the year-long sophomore organic chemistry lab, decided to eliminate the lab report, to redesign the labs, and to develop a sequence of assignments and instruction to teach the real genre of chemists: the scientific paper. Drawing on insights derived from Carter and Beaufort–that doing chemistry experiments, thinking like a chemist, and writing like a chemist are inseparable–they wanted to integrate writing into existing chemistry laboratory courses and not relegate it to a separate "writing in chemistry" course. In this way, students could write about experiments they perform in lab and thus have a stake in. They hoped that by writing real scientific papers as sophomores, students would be socialized more quickly into the scientific community; they hoped further that students' learning would transfer to increased proficiency and professionalism when they wrote senior theses.

It is important to note that numerous articles and books have been published on writing in chemistry (including Kovac and Sherwood 1999; Wallner and Latosi-Sawin 1999; Stoller, et. al. 2005; Burke, Greenbowe, and Hand 2006; Schepmann and Hughes 2006; Margerum, et. al. 2007). Perhaps the most helpful to us was a book published by Robinson, Stoller, Costanza-Robinson, and Jones (2008). However, the approach described in this paper differs substantially from these approaches because of the way that Alaimo and Langenhan have embedded writing instruction in a year-long sophomore organic chemistry lab, altered the labs to support inquiry, and tried to engage the full range of knowledge/skills needed to generate expert insider prose in a discipline.

From Lab Reports to Scientific Papers

Alaimo and Langenhan reasoned that if students were to write a professional-quality thesis in their senior year, then the required sophomore-level lab course in organic chemistry provided the perfect site for focused, sustained writing instruction early in the curriculum. Thus, Alaimo and Langenhan started their work by redesigning from scratch the existing year-long sophomore-level organic chemistry lab.

Historically, organic chemistry labs at Seattle University required students to complete a "cookbook" experiment to create a new substance and then to write a corresponding lab report. For example, students might work to convert an alcohol to an aldehyde via a chemical reaction. In lab, students performed the reaction, isolated the product, and then determined its characteristics using standard techniques and instrumentation. Such experiments helped students master technical skills, but they did not draw substantially upon subject matter knowledge and did little to promote critical thinking, let alone thinking like professional chemists.

After lab, students wrote lab reports containing many of the same sections as a scientific paper. However, these assignments bear little other resemblance to the written genres used by real chemists. The problem with conventional lab reports is that they encourage students to think and behave like students rather than like professionals. Because students know (or think they know) the expected outcome of the "cookbook" experiments, they chalk up any deviation from the expected outcome as "experimental error" with little thoughtful explanation. Also their assumption that the audience for their reports is the instructor contributes to a novice style. In many cases this assumption is highly visible: Students often refer to the instructor directly in their writing (e.g., "Professor Alaimo said we should use 1 M NaOH rather than the 1.2 M NaOH that the lab manual recommended"). But the deepest problem with lab reports—the most compelling reason why they represent a pseudo-genre—is that they focus on experiments that generate a single datum. No scientist would follow such a process. In fact, few things are considered *less* scientific than to attempt to write a compelling, well-argued paper based on singular runs of an experiment. In short, the lab report develops habits that students must *unlearn* if they are going to think and write like professional chemists.

In order to require scientific papers rather than lab reports, Alaimo and Langenhan made three substantial changes. They redesigned the sophomore organic experiments so that they promoted genuine inquiry resulting in enough data to be worth writing about; they designed sequences of writing assignments to teach the scientific paper over the course of a year; and they built in genuine writing instruction—employing well-designed assignments, examples, rubrics, and peer review—to help students develop "writing process knowledge."

Redesigning the Organic Chemistry Labs

In introductory organic chemistry lab, students learn five to eight widely agreed upon techniques that comprise the basic toolbox chemists use to perform organic chemistry laboratory investigations. In a typical experiment, the class might investigate how a panel of eight different substrate molecules reacts differently under a given set of reaction conditions. Such experiments can be found in all the commonly used textbooks for introductory organic chemistry lab courses. However, in a conventional cookbook lab, students are usually asked to test each substrate once and to record their observations. Alaimo and Langenhan found that this arrangement undermined their efforts to construct students as professionals.

A professional organic chemist would perform the same reaction on each substrate numerous times. Perhaps six, eight, or more replicates would be required per substrate, depending on the reliability of the data obtained (as assessed using basic statistical methods). Although a typical lab period of three hours seems to allow insufficient time for such a detailed study, Alaimo and Langenhan realized this problem could be easily surmounted. Instead of having each student perform eight reactions using eight *different* substrates, each student could run the *same* reaction in eight replicates. At the end of a class, students could then share their results—thus pooling data for all eight substrates—and assume responsibility for thinking about the collective lab data.

The advantages of this simple change are dramatic. Students start to realize why doing an experiment only once is problematic. Because the redesigned experiments require multiple replications investigating several substrates, no single "right answer" emerges. Rather, laboratory work yields multiple trends in data that are often puzzling both to students and instructors and that may be contaminated by experimental error. To interpret their data—and to convince their audience that their interpretations are valid—students must learn how scientists identify experimental error statistically and how statistical analysis can be used to discard an erroneous datum. In a cookbook lab, a student might make a single (faulty) run of an experiment and report confidently, "*tert*-Butyl chloride reacts faster than *n*-butyl chloride." The redesigned labs undermine this confidence, creating the need for evidence-based argument. Confronting true experimental error puts students in the center of a discourse community—as active scientists puzzling over data with other scientists—where they learn the important lesson that science is founded on reproducibility.

Designing and Sequencing Organic Chemistry Writing Assignments

As another means of helping students learn to think like a chemist, Alaimo and Langenhan designed writing assignments to match the progressive course structure just described. Scientific papers in organic chemistry are generally divided into six sections: Introduction, Experimental, Data & Results, Discussion, Conclusions, and References. Alaimo and Langenhan decided to address each section separately, teaching them in an order that both matched course structure and maximized student learning by progressing from lower to higher levels on Bloom's taxonomy (Bloom 1956). For reasons explained later in this paper, they taught the Experimental and References sections first, followed by the Data & Results section, since these components require skills relatively low on Bloom's taxonomy (knowledge and comprehension). Only in the second half of the year-long sequence did students begin tackling the Introduction, Discussion, and Conclusion sections, which demand the higher-level skills of analysis, synthesis, and evaluation as well as all the skills/knowledge identified by Beaufort as integral to expert insider prose.

Seattle University operates on the quarter system; thus, the year-long lab consists of three quarter-long courses. Each course includes three or four writing assignments, which provide students ample practice on the sections of current focus. Each quarter, the final writing assignment combines all the sections learned to date in a single paper. At the end of the third course, the final assignment is to write a complete scientific paper.

Assignment sheets for each section of the scientific paper contain learning objectives, specific instructions, recommended content, and examples, accompanied with a scaled rubric that indicates assessment criteria. (See Appendix A for excerpts from handouts and Appendix B for a rubric.) Students are encouraged to use the rubrics to guide their writing and to conduct peer-review. Besides ensuring that students focus on the appropriate content, rubrics help to build writing process knowledge as described later in this paper. Perhaps the most important feature of the instructional handouts is their consistent focus on a professional audience. When students write to their instructor as audience, they see lab reports as homework, not as professional documents. In contrast, imagining professional scientists as the audience orients students to adopt the persona of expert insiders who are communicating with other expert insiders. Our rubric (Appendix B) emphasizes audience by demanding that students provide scientific context, construct well-developed ideas, and build persuasive arguments for scientific readers who have an interest in, but no prior knowledge of, the specific experiment. Since Alaimo and Langenhan consistently emphasize the importance of audience through instruction, assignment sheets, and rubrics, they have encountered few difficulties prompting students to write for a professional audience. While students recognize that their instructor is the actual reader, they seem able to understand the pedagogical value of writing toward an imagined audience of professionals.

How the Learning Process Unfolds throughout the Year-Long Lab

The process just described introduces students gradually to the demands of professional writing. The first quarter of the year-long lab focuses on experimental techniques and analysis using instruments. To match this course content, students learn how to write the Experimental section and References section of a scientific paper. Students are taught to describe their experimental procedures in ways that are sensitive to old and new information for professional chemists. (See Appendix A for an excerpt from the instructional handout for the Experimental section.) Students find writing the Experimental section relatively easy because they need only describe their actual procedures in the lab without doing higher order analysis. Similarly, writing a high quality References section is mostly about understanding and using the conventions of the genre.

During the second and third quarters, students apply their newly gained technical skills to more challenging experiments. They next learn to write the Data & Results section, which requires students to report and display their experimental data in a professional style (table, graph, figure, etc.). In a workshop, students learn to sort through the data recorded in their lab notebooks, applying statistical analysis to determine the quality of their data, calculate error, and assess significance. They then learn ways to organize their data to help identify trends related to the aim or hypothesis of an experiment. Identifying trends is quite challenging because this task draws primarily upon synthesis and evaluation, intellectual skills that are high on Bloom's taxonomy. However, once trends are identified the actual formatting of the Data & Results section is relatively easy. An instructional handout communicates the genre-specific conventions expert chemists use to present their data in tables, graphs, and figures.

At this point, students are ready to tackle the argumentative portion of a scientific report—the Discussion section. This section draws heavily upon high-level Bloom skills, while also requiring the overlapping kinds of knowledge identified in Beaufort's Venn diagram: subject matter knowledge, rhetorical knowledge, genre knowledge, and discourse community knowledge. Within the Discussion section, students must analyze data, apply theoretical models, substantiate their claims, and qualify their arguments in light of contradictory data. (See Appendix A for an excerpt from the instructional handout for the Discussion section.) Students quickly learn that they cannot write a persuasive discussion section if they have not first spent time critically interpreting their data and analyzing it in light of their experimental aim. In this way, the demands of writing the discussion section of a scientific paper foster professional thinking.

Later, when the Introduction section is introduced, students see how the argument produced in the Discussion section connects rhetorically with the Introduction section, which provides scientific background, establishes the context and relevance of the study through a literature review, and identifies the experimental aim. Because introductions require the highest level of both critical thinking and discourse community knowledge, they are addressed late in the year when students have learned nearly a year's worth of organic chemistry. To teach a review of the scientific literature, Alaimo and Langenhan conduct a short workshop on *SciFinder Scholar*, a leading electronic tool for searching the chemical literature. For the first Introduction assignment, Alaimo and Langenhan provide appropriate articles. Later students are required to conduct their own literature review to find articles. While students are learning to write Introduction sections, the instructors also address Conclusion sections, which are relatively simple because they involve no new critical thinking. They require the student simply to restate the scientific aim and summarize the arguments made in the Discussion section.

How Students Develop "Writing Process Knowledge"

Alaimo and Langenhan employ three tools to build student writing process knowledge: analytical grading rubrics, written feedback on writing assignments, and required revisions on most assignments.

To communicate expectations and grading criteria to students, Alaimo and Langenhan worked with Nichols and Bean to design rubrics for each of the six sections of a scientific paper as well as a comprehensive rubric for a complete scientific paper (Appendix B). To promote writing process knowledge, Alaimo and Langenhan also require a revision on most assigned papers since much learning occurs as students work to improve their own writing. In the first round of feedback, students receive a graded rubric as well as instructor comments on the draft, mostly comprised of what Elbow and Belanoff (1999) call "readerly" comments, which note places where the reader gets confused, needs more details, or finds a particularly insightful passage. Alaimo and

Langenhan provide “writerly” feedback, such as circling errors or rewriting a sentence, on only a small portion of the draft. The purpose of this approach is to provide students with enough genre-specific guidance to enable them to assimilate a professional style but not so much that they can achieve success simply by inputting faculty suggestions. The graded rubric, readerly comments, and limited writerly comments on the draft encourage students to focus more on meaning and professional style rather than on simply correcting errors. The final grade on each assignment is a weighted average comprised of two-thirds of the original draft grade plus one-third of the revised draft grade. The strong weighting of the first draft ensures that students work to improve their writing before turning in the initial assignment; however, enough weight is placed on revision to ensure that students rewrite carefully. Writing assignments are spaced so that students can apply the learning gains made in one assignment to the next assignment. This arrangement ensures that students progressively build their writing skills throughout the year-long course.

How Writing the Scientific Paper Constructs Students as Scientists

Alaimo and Langenhan have observed marked changes in student behavior as a result of the redesigned organic lab course. Because each individual student generates data for the entire class and because the multiple replicates must be internally consistent before students can leave the lab, students work diligently to obtain quality data. Moreover, because the students collectively generate large quantities of data that may be contaminated by error, they need to learn research skills that few organic laboratory courses cover—namely how to use electronic spreadsheets to perform simple statistical analyses. This cooperative focus on puzzling data produces engaged discussion unlike anything in a traditional cookbook lab where students either produce the right answer or dismiss wrong answers as “experimental error.” Now students become genuinely excited when multiple replicates show internal consistency or when inconsistencies can be analyzed statistically. The redesigned labs show students why scientists avoid over-interpreting a single datum. Most importantly, they teach students how and why scientists construct a well-reasoned argument supported by richly analyzed evidence.

As the year progresses, students become increasingly proficient at writing in a professional style, adopting genre-specific conventions for figure design, table formatting, and naming, and understanding the persuasive purpose of a scientific paper. Alaimo and Langenhan assessed the success of the redesigned lab by scoring students’ final assignment (the full scientific paper) against the criteria shown on the complete rubric

(Appendix B). The average score on this 100-point rubric was 89 with a range or 99-65. These scores indicate that, on average, students produced work mostly in the highest categories on the grading rubric, suggesting the success of the lab in helping students join the discourse community of chemists.

Finally, students recognize that their growing skill in scientific writing helps them feel more connected to the community of scientists. Students' appreciation of the writing component of the lab is clearly reflected in their anonymous end-of-year comments, such as the following:

- "I'm very glad we focus on scientific writing."
- "I found the writing more helpful in understanding deeply the concepts in class because they forced me to be active in my chemistry thinking."
- "Scientific writing is awesome! I feel more motivated because this is something that is applicable to real-life research."

Importance and Future Directions

The lab course innovations described in this paper are important because they address the question of how chemistry educators can better prepare undergraduates for professional life by teaching them that writing like a chemist means thinking like a chemist. The kind of writing and thinking taught in these redesigned labs is different in kind from that elicited by cookbook labs and pseudo-academic lab reports. Beyond its direct value to students, the importance of this work to the chemistry community is highlighted by the excitement this project has generated among both undergraduate and graduate educators in chemistry. For example, a presentation at a recent National Meeting of the American Chemical Society (Alaimo, Langenhan, and Loertscher 2007) identified numerous potential collaborators including some from top chemistry graduate programs. Because the approach described here depends upon the integration of inquiry-based laboratory experiments, writing instruction embedded in the context of a disciplinary course, and numerous feedback-revision cycles, it is most appropriate for other year-long laboratory courses with a similar emphasis on writing. It is likely more difficult to implement our approach in a course that is either shorter (one semester) or separated from disciplinary inquiry (such as a stand-alone "writing in chemistry" course).

It is important to note that we are currently working on a long-term, longitudinal study of the effectiveness of this program. Alaimo and Langenhan plan to measure whether the improvements in writing and thinking that have been observed in the organic lab course will transfer to later courses. Specifically, they would like to know how much student learning in the sophomore organic chemistry lab will affect later performance in physical chemistry, biochemistry, and the senior capstone course. The chemistry department has recently received grant funding to undertake this longitudinal study, which should contribute significantly to the national dialogue on transfer of learning. In the meantime, we are confident that the redesigned curriculum has produced significant changes in our students. Writing real scientific papers seems to have transformed their view of their laboratory work, led to more responsible treatment of data, and increased their understanding of the scientific paper as persuasion. Most importantly, writing real scientific papers has helped them become, we believe, better young scientists.

APPENDIX A: EXCERPTS FROM ASSIGNMENT HANDOUTS

WRITING AN EXPERIMENTAL SECTION

What is an experimental section?

The experimental procedure section contains an explicit account of the procedure(s) you performed. The purpose of this section is to provide other scientists the information they need to evaluate your methods or repeat your experiment. A complete experimental section contains a description of each procedure. If the procedure is new you must describe it in a stepwise, detailed fashion. If the procedure has been published previously in a standard journal or book, a reference to the procedure is all that is necessary. Within the context of a logical description of the experimental procedure, where relevant you should include a) equipment that was used, b) materials that were used, and c) the sources of chemicals that were used.

Who is reading your experimental procedure?

The audience for an experimental section is other scientists who have no prior knowledge of your experiment and who have the same or greater chemistry education level as you. Therefore you must carefully consider what knowledge you can assume and the level of detail that is necessary and sufficient for clear and concise communication.

Examples of Experimental Sections

Below are provided three examples of experimental procedures that describe a titration to determine the concentration of acetic acid in vinegar.

Example 1: A well-written procedure

A titration to determine the concentration of acetic acid in vinegar was performed in triplicate using standard titration procedures and equipment.[1] *The solution used to titrate the vinegar was 1.0 M aqueous NaOH. The vinegar (Heinz® distilled white vinegar, 4.5 %) was diluted with 5 volumes of water before titration. A phenolphthalein indicator was used to determine the endpoint of the titration.*

Example 2: Too much information

Using a 10 mL graduated cylinder, 5 mL of vinegar were transferred to a 250 mL Erlenmeyer flask. The brand of vinegar was recorded (Heinz® distilled white vinegar) as well as the percent acetic acid stated on the label (4.5 %). The volume of the vinegar sample was recorded. Water (25 mL) was added to the vinegar to increase the volume of the solution for titration. Three drops of phenolphthalein indicator were added to the flask. To a buret was added 50 mL of 1.0 M NaOH solution. The vinegar solution was placed under the buret on a piece of white paper. The NaOH solution was slowly added by carefully opening and closing the stopcock and swirling the flask until the pink color barely persisted. The buret reading of NaOH was recorded. The buret was then filled again and the titration was performed two more times with samples of the same type of vinegar.

- The author does not assume a reasonable audience; they are over-explaining everything (e.g., anyone who has done a titration knows that you add aq. NaOH to the buret and use white paper to better visualize the endpoint).
- This procedural account is very detailed and chronological, more like a lab notebook entry.

Example 3: Inappropriate colloquial language

I performed a titration to determine the concentration of acetic acid in vinegar. I used standard titration procedures and equipment as described in the textbook on page 22. Since there wasn't any 1.0 M NaOH as described in the textbook, PJ said that we should use 0.75 M NaOH instead. The vinegar was Heinz® distilled white vinegar and had 4.5 % acetic acid in it. This vinegar was diluted with 5 volumes of water before titration. I used a phenolphthalein indicator to determine the endpoint of the titration.

- In scientific writing, passive voice is generally preferred over first person.
- "…in the textbook on page 22" is not a properly formatted scientific reference.
- A quotation from a conversation (i.e., "PJ said…") or use of pronouns is inappropriate for the formal style required in scientific writing.

What is a discussion section?

A scientific paper is a specialized form of persuasive writing. In the discussion section, the author interprets the information contained in the data/results section to construct a persuasive argument that addresses the aims provided in the introduction section.

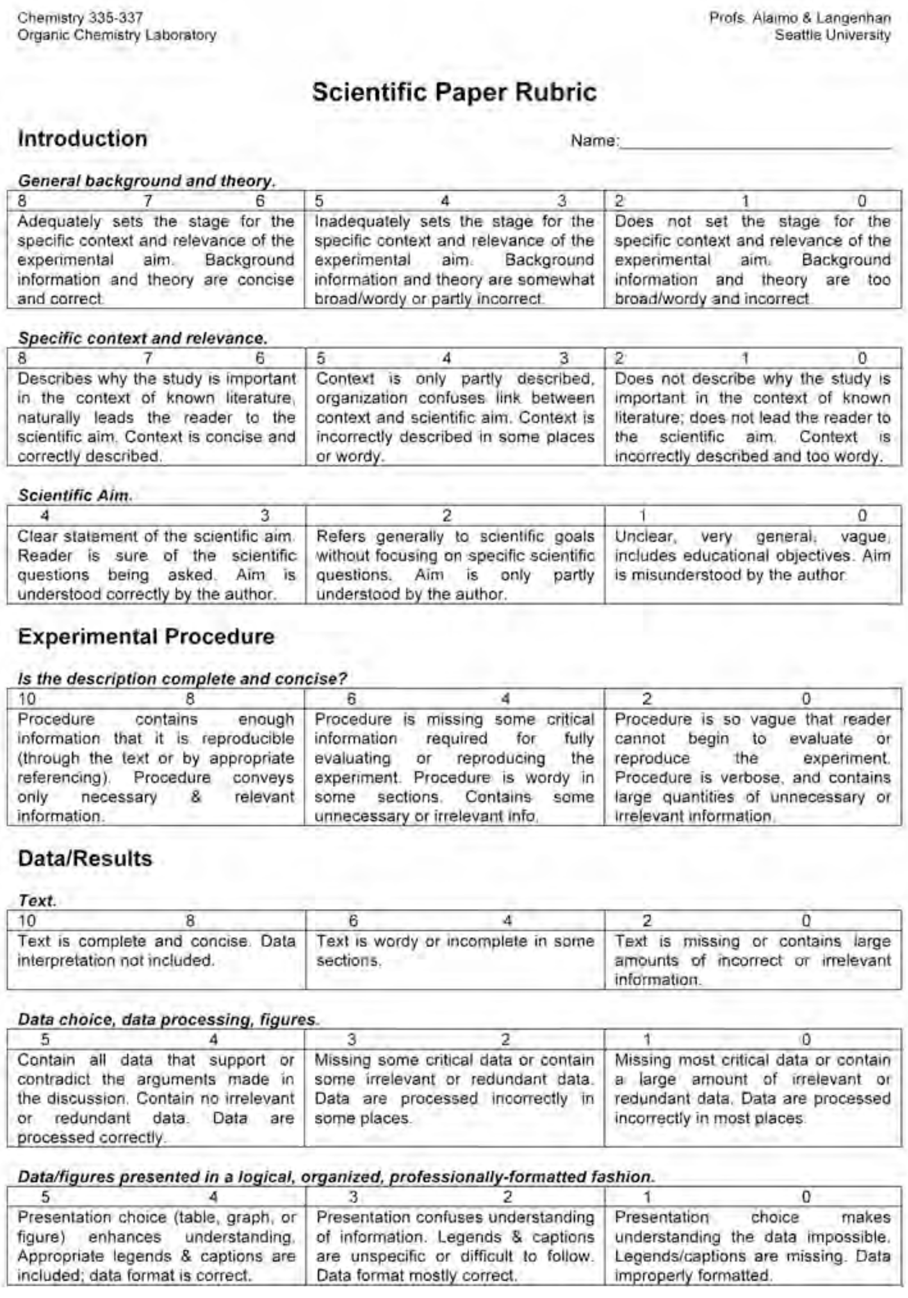
Imagine yourself as a lawyer trying to convince a jury of scientists about what your findings *mean*. To do this, you must **first** take time to interpret critically your data/results. Your data section will contain all data that support *or contradict* the arguments you will make in your discussion. As an ethical scientist, you must consider whether contradictory data undermine your ideas, or whether the contradictory data can be reasonably explained. If data undermine your argument, you must qualify your argument in a manner consistent with the contradictory data, or not make the argument at all. If you have a reasonable explanation for contradictory data you should provide it, but avoid resorting to unsubstantiated claims for why certain data are invalid. For example, students often discount certain results because of "human error," without providing evidence of specific circumstances when error was a factor. If you wish to argue that error was the cause of certain data, you must provide evidence and describe the error specifically.

Once you have interpreted your data and developed your ideas, you are ready to communicate to the jury, the scientific community, by writing your discussion section. Your discussion must be well organized and logical, progressively making specific points using specific data, until you have built a convincing case.

Who is reading your discussion section?

The audience for a discussion section is other scientists who have no prior knowledge of your experiment and who have the same or greater chemistry education level as you. You must explain your interpretation of your data/results to this audience; *the burden of proof is on you to convince them your arguments are justified.*

APPENDIX B: SCIENTIFIC PAPER GRADING RUBRIC



Chemistry 335-337
Organic Chemistry Laboratory

Profs. Alaimo & Langenhan
Seattle University

Scientific Paper Rubric

Introduction

Name:______________________________

General background and theory.

8 7 6	5 4 3	2 1 0
Adequately sets the stage for the specific context and relevance of the experimental aim. Background information and theory are concise and correct.	Inadequately sets the stage for the specific context and relevance of the experimental aim. Background information and theory are somewhat broad/wordy or partly incorrect.	Does not set the stage for the specific context and relevance of the experimental aim. Background information and theory are too broad/wordy and incorrect.

Specific context and relevance.

8 7 6	5 4 3	2 1 0
Describes why the study is important in the context of known literature, naturally leads the reader to the scientific aim. Context is concise and correctly described.	Context is only partly described, organization confuses link between context and scientific aim. Context is incorrectly described in some places or wordy.	Does not describe why the study is important in the context of known literature; does not lead the reader to the scientific aim. Context is incorrectly described and too wordy.

Scientific Aim.

4 3	2	1 0
Clear statement of the scientific aim. Reader is sure of the scientific questions being asked. Aim is understood correctly by the author.	Refers generally to scientific goals without focusing on specific scientific questions. Aim is only partly understood by the author.	Unclear, very general, vague, includes educational objectives. Aim is misunderstood by the author.

Experimental Procedure

Is the description complete and concise?

10 8	6 4	2 0
Procedure contains enough information that it is reproducible (through the text or by appropriate referencing). Procedure conveys only necessary & relevant information.	Procedure is missing some critical information required for fully evaluating or reproducing the experiment. Procedure is wordy in some sections. Contains some unnecessary or irrelevant info.	Procedure is so vague that reader cannot begin to evaluate or reproduce the experiment. Procedure is verbose, and contains large quantities of unnecessary or irrelevant information.

Data/Results

Text.

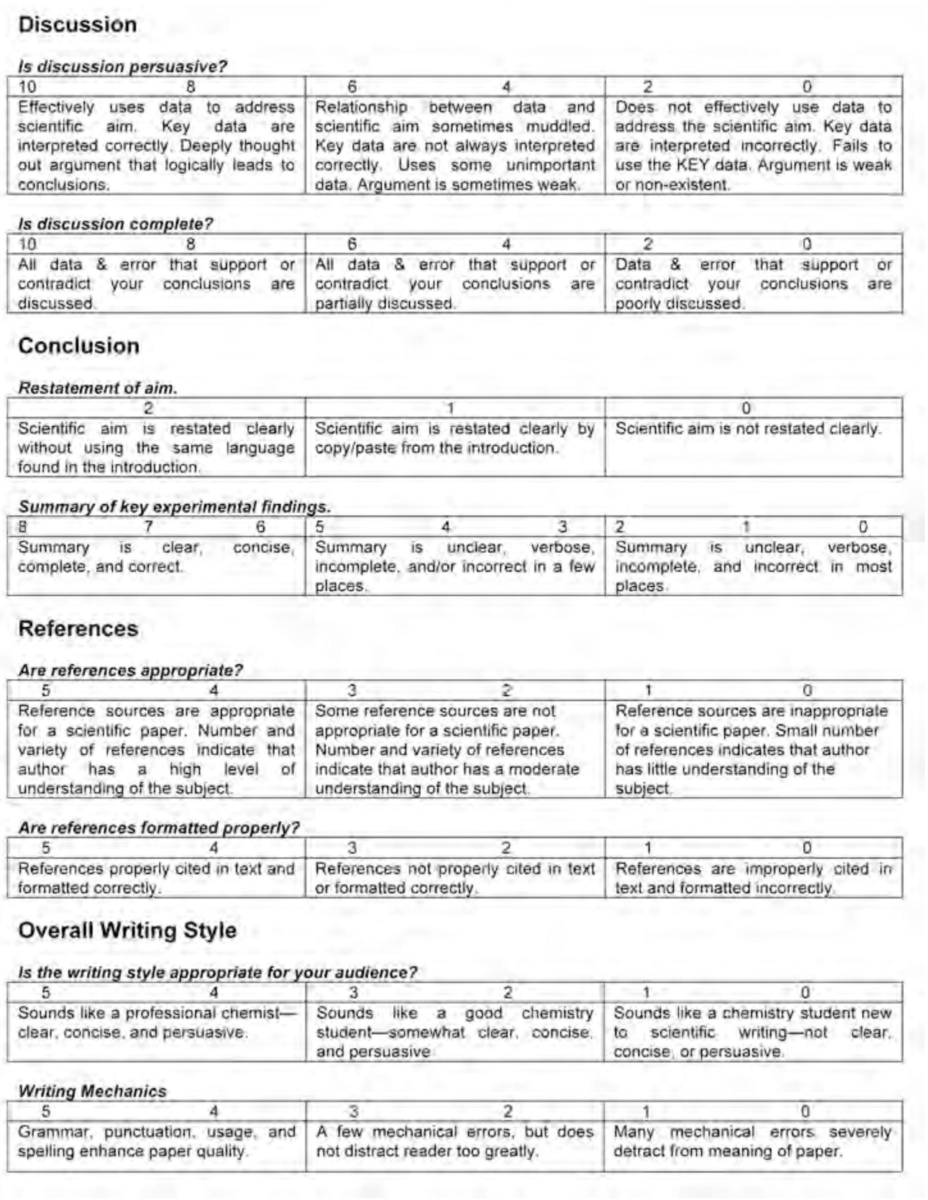
10 8	6 4	2 0
Text is complete and concise. Data interpretation not included.	Text is wordy or incomplete in some sections.	Text is missing or contains large amounts of incorrect or irrelevant information.

Data choice, data processing, figures.

5 4	3 2	1 0
Contain all data that support or contradict the arguments made in the discussion. Contain no irrelevant or redundant data. Data are processed correctly.	Missing some critical data or contain some irrelevant or redundant data. Data are processed incorrectly in some places.	Missing most critical data or contain a large amount of irrelevant or redundant data. Data are processed incorrectly in most places.

Data/figures presented in a logical, organized, professionally-formatted fashion.

5 4	3 2	1 0
Presentation choice (table, graph, or figure) enhances understanding. Appropriate legends & captions are included; data format is correct.	Presentation confuses understanding of information. Legends & captions are unspecific or difficult to follow. Data format mostly correct.	Presentation choice makes understanding the data impossible. Legends/captions are missing. Data improperly formatted.



Discussion

Is discussion persuasive?

10 8	6 4	2 0
Effectively uses data to address scientific aim. Key data are interpreted correctly. Deeply thought out argument that logically leads to conclusions.	Relationship between data and scientific aim sometimes muddled. Key data are not always interpreted correctly. Uses some unimportant data. Argument is sometimes weak.	Does not effectively use data to address the scientific aim. Key data are interpreted incorrectly. Fails to use the KEY data. Argument is weak or non-existent.

Is discussion complete?

10 8	6 4	2 0
All data & error that support or contradict your conclusions are discussed.	All data & error that support or contradict your conclusions are partially discussed.	Data & error that support or contradict your conclusions are poorly discussed.

Conclusion

Restatement of aim.

2	1	0
Scientific aim is restated clearly without using the same language found in the introduction.	Scientific aim is restated clearly by copy/paste from the introduction.	Scientific aim is not restated clearly.

Summary of key experimental findings.

8 7 6	5 4 3	2 1 0
Summary is clear, concise, complete, and correct.	Summary is unclear, verbose, incomplete, and/or incorrect in a few places.	Summary is unclear, verbose, incomplete, and incorrect in most places.

References

Are references appropriate?

5 4	3 2	1 0
Reference sources are appropriate for a scientific paper. Number and variety of references indicate that author has a high level of understanding of the subject.	Some reference sources are not appropriate for a scientific paper. Number and variety of references indicate that author has a moderate understanding of the subject.	Reference sources are inappropriate for a scientific paper. Small number of references indicates that author has little understanding of the subject.

Are references formatted properly?

5 4	3 2	1 0
References properly cited in text and formatted correctly.	References not properly cited in text or formatted correctly.	References are improperly cited in text and formatted incorrectly.

Overall Writing Style

Is the writing style appropriate for your audience?

5 4	3 2	1 0
Sounds like a professional chemist—clear, concise, and persuasive.	Sounds like a good chemistry student—somewhat clear, concise, and persuasive	Sounds like a chemistry student new to scientific writing—not clear, concise, or persuasive.

Writing Mechanics

5 4	3 2	1 0
Grammar, punctuation, usage, and spelling enhance paper quality.	A few mechanical errors, but does not distract reader too greatly.	Many mechanical errors severely detract from meaning of paper.

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