Targeting Report Expectations to Develop Presentation, Analysis, and Evaluation Skills in the Analytical Chemistry Curriculum

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Abstract

In our experience teaching Analytical Chemistry, our expectations concerning laboratory reports have been disconnected from student performance. Instead of students advancing to the next level in their ability to present, analyze, and evaluate scientific data commensurate with consistent professional development through their chemistry curricula, students' abilities in these areas appear to plateau. Therefore, we established a series of laboratory exercises that require graduated performance with each subsequent assignment. Specifically, we expect students to complete worksheets targeted to build specific skills for a given week (e.g., data representations in figures, construction of tables, error propagation, etc.). On a less frequent basis, we require that students write a report, which encourages them to integrate skills acquired from the worksheets into a formal writing assignment. To assess and foster student improvement in data presentation, analysis, and evaluation, we have developed a set of rubrics that are shared with students. After one quarter of implementation, we have observed advancement in student performance in some areas.

Key Words

Education Methods

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Introduction

Analytical Chemistry I is a sophomore level course required of chemistry and chemical engineering majors. It has a significant laboratory component in which students are trained to collect quantitative data with a high degree of precision and accuracy. The course provides an excellent training ground for students to report and evaluate critically their results in a concise manner consistent with professional standards. It is disheartening to make comments on laboratory reports only to see the same mistakes repeated on subsequent reports in this and later courses. In addition, assessing student performance in the areas of the mechanics of data presentation (tables and figures) and their evaluation of the quality of their data (precision and accuracy) is very time consuming for large classes. Therefore, our goal was to improve the quality of the laboratory reports submitted by students and teach them habits that will be carried to future courses and professional settings.

When presenting a new topic, it is not uncommon to start with the simplest concepts and add the more complex aspects as the students' skills increase. In 1985, M. Kiniry and E. Strenski identified a hierarchy of skills required for effective written communication. In order of complexity, these are: listing, defining, seriating, classifying, summarizing, comparing/contrasting, analyzing, and presenting an academic argument[1]. In 2001, L. Tilstra presented a way to apply the concept of hierarchical communication skills to facilitate the teaching of writing skills in a General Chemistry laboratory course[2]. She describes a series of assignments in which students are given a description of a particular element of written communication and then two opportunities during the quarter to demonstrate their skill. As the quarter progresses, the elements become more complex; starting with listing sections of a journal article, followed by preparing a chronological report of observations (seriation), preparing a plot from specific guidelines, preparing a data table (classifying and organizing data), and—finally—analyzing results (with and without guiding questions). Although this method is an effective way to teach communication skills, it does not address the need to streamline the grading process so that students receive feedback in a timely fashion.

We present an approach we implemented in our existing sequence of Analytical Chemistry I laboratory experiments in which we used a hierarchical approach to developing particular skill sets (e.g, data presentation in figures, construction of tables, propagation of error and evaluation of accuracy and precision). Descriptions of these elements were developed, and expectations for student performance were graduated with each subsequent assignment and assessed using rubrics. The effectiveness of this approach on student learning was assessed by administering a quiz designed to measure students' ability to identify elements of data presentation and evaluate critically a set of analytical data with respect to accuracy and precision; the quiz was administered at the beginning and end of the course.

Description of method

We identified the specific elements of presentation, analysis, and evaluation that students were expected to learn during this course. With respect to presentation, we chose to emphasize three elements: 1) preparation of correctly formatted figures and plots, 2) preparation of correctly formatted and labeled tables, and 3) describing an experimental procedure. The first two are relatively low on the complexity hierarchy; they require accurately following a specific list of directions. The third is a bit more complex, but certainly not beyond the expected ability of college sophomores.

With respect to analysis and evaluation, we selected four elements: 1) identifying goals and objectives, 2) reporting results with uncertainty and comparing those results with known values, 3) identifying sources of error and predicting the effect(s) of these sources of error on the experimental values, and 4) identifying which source(s) of error is (are) affecting a specific result. The first element is high on the complexity hierarchy, but was emphasized early in the course because of its importance with respect to the technical content of the laboratory. The second is a technical skill, not trivial to do, but well-defined. The third is by far the most challenging for students of all levels, while the fourth follows rather naturally from the third.

Technical communication elements (format of tables, figures, and plots) were based on guidelines set forth by the Style Guide of the American Chemical Society; these represent the format generally accepted by the fields of chemistry and chemical engineering. Expectations regarding analysis elements were communicated to students through detailed, descriptive documents prepared and distributed to the students (see Appendix I for one example).

The goal was to have two submissions for each of the seven elements. The first submission for a given element was graded and returned to the students before the second submission was required. The schedule we used is presented in Table I.

Grading rubrics were designed such that format was separated from technical content to help students recognize that format is an important part of communicating results and that an error on technical content cannot be hidden in perfect formatting. Students did not receive copies of the rubrics before they completed assignments, but rubrics were mapped to specific points of the detailed descriptive document. The challenge was to present students with enough detail to help them learn the element while encouraging them to think for themselves. The three rubrics are presented in Appendix II demonstrate rubrics designed at the beginning, middle, and end of the quarter.

Table I. Schedule for the assessment of essential elements of presentation, analysis, and evaluation in the Analytical Chemistry I course.

Element	First submission due	First submission graded & returned	Second submission due
Figures	Week 1 Experiment A	Week 2	Week 3 Experiment C
Goals & Objectives	Week 2 Experiment B	Week 3	Week 5 or 4 Experiment E
Tables	Week 3 Experiment C	Week 4	Week 5 or 4 Experiment E
Describing Procedure	Week 4 or 5 Experiment D	Week 6	Week 8 Experiment H
Reporting results with uncertainty (format) and comparing results with known values.	Week 5 or 4 Experiment E	Week 6	Week 8 Experiment H
Identifying sources of error and predicting the effect of these sources of error on the experimental value.	Week 6 Experiment F	Week 7	Week 8 Experiment H
Identifying which source of error is affecting a specific result	Week 8 Experiment H		

Results

Forty representative plots/figures initially submitted by students were assessed by one reviewer using the rubric presented in Appendix II. The average student score was 64.8 % (3.27 out of 5). The second set of plots/figures submitted by students (assessed by the same reviewer) received an average score of 2.52 out of 5 points (50.4%). If the first three details of the rubric for Figures & Plots are removed from the analysis, students scores improve, albeit slightly, from 2.13 out of 3 for the first submission to 2.32 out of 3 for the second submission. It was concluded that the rubric was not well-designed because it was difficult for the reviewer to use and students appeared to gain little from the results. Preparation of properly formatted tables was assessed using newly designed rubrics (Appendix II). In Table II, we present the results of six out of forty table submissions. The average score for the first assessment of data tables for these six was 3.37_5. The average score for the second assessment of data tables for the same six groups was 3.87_5. Two of the groups had a lower score for their second submission by 0.25. It is not unreasonable to assume that the two groups for whom the score went down from first to second assessment did not look at the first graded report before they submitted the second.

The results of the Analytical Data Assessment quiz administered at the beginning and end of the course also provide information on student learning in the areas of constructing tables and figures. Specifically, questions 3 and 4 ask students to evaluate the appropriateness of a table and figure, respectively. The average score on question 3 was 60 % at the beginning of the course and 80% at the end. The average score on question 4 was 20% at the beginning of the course and 67 % at the conclusion of the course. These results demonstrate improvement in the abilities of students to recognize the aspects of a well presented table and/or figure.

During the second week of the quarter, students were given a description of what goals and objectives were. They were asked to write goals and objectives in every report. It is hard to assess for improvement because the initial scores were quite high. For example, in experiment B the average score for goals and objectives was 3.9/5. The average remained close to this score for every report in which students were required to report goals and objectives.

Table II. A summary of students scores for the first and second submission of a data table. The scores reflect the total of the five elements presented in the rubric in Appendix II.

	First submission (out of 5.00)	Second submission (out of 5.00)
Group A	3.50	4.50
Group B	3.75	3.50
Group C	2.00	3.50
Group D	4.25	5.00
Group E	3.25	3.00
Group F	3.50	3.75

The higher level analysis and evaluation elements are difficult to assess. The ability of students to consider experimental uncertainty, agreement with an accepted value and identifying bias in an experimental result was assessed by questions 1 and 2 on the Analytical Data Assessment quiz. The average score on question 1 was 20 % at the beginning of the course and 90% at the end. The average score on question 2 was 20% at the beginning of the course and 75 % at the conclusion. These results demonstrate significant improvement in the abilities of students to recognize agreement between experimental and accepted values in light of experimental uncertainty and identify the presence of bias in an experimental result, indicating their analysis and evaluation skills improved.

Conclusions

We implemented an approach to improving report quality for the laboratory portion of an analytical chemistry course that uses a hierarchical approach of identifying the various aspects of presenting and analyzing analytical data (e.g, data presentation in figures, construction of tables, propagation of error and evaluation of accuracy and precision). Descriptions of these elements were developed, and expectations for student performance were graduated with each subsequent assignment and assessed using rubrics. We concluded that our use of the rubric on constructing tables helped to improve student performance, and we plan to change that for presenting figures so that it is of similar format. An analytical data assessment quiz was administered at the beginning and end of the course to determine if student's abilities in the areas of data presentation and increased. The overall scores on the assessment quiz improved from a beginning score of 43% to a score of 75% at the conclusion of the course, indicating that students improved in the areas of technical communication and analytical evaluation. By the very nature of the course, it is impossible to separate learning that takes place in the lecture portion from that that takes place in the laboratory. Therefore, it cannot be concluded unequivocally that the approach we took on the laboratory reports is primarily responsible for student success. However, the approach to the reports no doubt contributed to student understanding and performance, especially in the area of data presentation.

Comments on Institute evaluations of the lab course generally focus on the applicability of selected experiments to course content rather than our assessment of the laboratory reports. Comments that are made in this regard tend to focus on the work load associated with putting together a report. We are attempting to address this by using worksheets more often with fewer formalized reports required.

The majority of students who take this course are chemical engineers. However, we have not attempted to tailor our report requirements to fit directly what is required in upper level chemical engineering courses. These students will be instructed of such requirements in the chemical engineering courses, and we would be doing a disservice to students from other majors. However, our approach stresses that requirements for tables and figures are always present, and one must be aware of those given the particular setting. Also, our approach requires that students pay attention to detail and recognize that all measurements and results have associated with them an inherent uncertainty and must be evaluated in that light. This is valuable for all majors in technical fields.

We plan to implement and assess this approach again.

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APPENDIX I: An example of a descriptive document

TABLES

One of the most efficient methods used to communicate technical information is by means of a ***data table***. While you have all seen examples of well-organized, legible data tables, few of you have had a great deal of practice constructing one from scratch. The construction of a good data table requires knowing what the important features are.

I. When to use Tables

Tables are to be used when the data are precise numbers, when there are too many to be presented clearly in the narrative, or when relationships between datum can be more clearly conveyed in a table than in the narrative. Tables should supplement, not duplicate, text and figures. If data is not treated theoretically in the report, or if the material is not a major topic of discussion, do not present it in tables.

II. How to Construct Tables

There are two kinds of tables: informal and formal. An informal table is one that consists of three to five lines and is no more than four columns wide. Informal tables may be placed in text following an introductory sentence. They are not given titles or numbers. Papers that report experimental results seldom use informal tables.

A formal table should consist of at least three columns, and the center and right columns must refer back to the left column. If there are only two columns, the material should be written as narrative. If there are three columns, but they do not relate to each other, perhaps the material is really a list of items and not a table at all.

Tables should be simple and concise, but many small tables may be more cumbersome and less informative than one large one. Combining is usually possible when the same column is repeated in separate tables. Use symbols and abbreviations that are consistent among tables and between tables and text.

Numbering Tables. Number formal tables sequentially with Roman numerals, in order of discussion in the text. [Note: in some fields of study, tables are numbered sequentially with Arabic numerals.] Every table must be cited in the text.

Title. Every table must have a brief title that describes its contents. The title should be complete enough to be understood without referring to the text, and it should not contain new information that is not in the text. Put details in footnotes, not in the title.

Column Headings. Every column must have a heading that describes the material below it. Keep headings to two lines, use abbreviations and symbols. Name the parameter being measured and indicate the unit of measure after a comma. A unit of measure is not an acceptable column heading.

Columns. The leftmost column is called the stub column. All other columns refer back to it. Main stub entries may also have subentries that should be indented. Be sure that all columns are really necessary. If there are no data in most of the entries of a column, it probably should be deleted. If the entries are all the same, the column should be replaced with a footnote that says "in all cases, the value was . . . " Do not use ditto marks or the word ditto. Define nonstandard abbreviations in footnotes. Whenever possible, numerical data should be entered such that the decimal points are vertically aligned. Uncertainty should be reported in the same notation as that used for the value. (It is not appropriate to mix general and scientific notation.)

Footnotes. Explanatory material that refers to the whole table and to specific entries belongs in footnotes. Footnotes should be written as narrative, in paragraph form, using standard punctuation. Material that refers to the whole table might be: units of measure, explanations of abbreviations and symbols, sources of data or other citations. Material that refers to specific entries might be: units of measure that are too long to fit in the column heading, explanations of abbreviations and symbols used with one or two entries, statistical significance of entries.

APPENDIX II: Three examples of rubrics from the course

1. The first example shows a poorly designed rubric. Because the second and third items are linked to the first item, it is difficult to know what a 'zero' means for these two.

GRADING RUBRIC FOR FIGURES & PLOTS

Title or caption:	0	0.25	0.5
-is the caption in the correct location?	0	0.25	0.5
-is the caption appropriately detailed?	0	0.5	1.0
Dependent variable is on the y axis.	0	0.25	0.5
Are the axis labeled correctly (title & units).	0	0.25	0.5
Legend is present if appropriate, absent if appropriate	0.	0.25	0.5
Correct choice between lines, symbols, or both.	0	0.25	0.5
Range is appropriate (minimizes white space on the plot).	0	0.25	0.5
Plot size is appropriate (at least half a page).	0	0.25	0.5

2. A modified approach to designing rubrics was used. This rubric is clearly mapped to the description presented in Appendix I.

GRADING RUBRIC FOR TABLES Name________________________

With the exception of the first element presented below, only one of the tables you submitted will be graded for format. The table selected for format evaluation will be clearly identified.

	Excellent (full)	Adequate (half)	Unacceptable (zero)
____ 0.5	Tables are numbered sequentially with Roman Numerals, e.g. **Table I.**	Tables are numbered, but either not sequentially or not with Roman Numerals	Tables are not numbered.
____ 1	The table contains at least three columns, and all columns refer back to the left-most column	The table contains three columns	The table contains fewer than three columns
____ 1	The title is complete enough to be understood without referring to any other text.	The title describes what is in the table, but is not sufficiently complete to stand on its own.	There is no title.
____ 0.5	The title is above the table, left-justified in a line that continues the left-justification of the left-most column of the table.	The title is above the table, centered or not aligned with the left-hand side of the table.	The title is below the table.
____ 1	Columns have headings that describe the material beneath them, units of measure are included.	Columns have headings, but do not include both description AND units of measure.	Columns have no headings
____ 0.5	Columns have data in most or all entries	One or two columns have many empty rows	Many columns have mostly empty rows.
____ 0.5	Footnotes are used as necessary to provide clarity wrt • Units of measure that don't fit in the heading. • Explanations of abbreviations and symbols. • Statistical significance of entries.	Footnotes are used for one or two of the items identified to the left.	Footnotes are not used, although they should have been.

Note: The rubric presented above does not assess your ability to determine whether or not a table is appropriate. That decision has been made for you in the laboratory worksheet; you are specifically directed to create tables to present certain specific information. Moreover, it is accepted that every table you present for these reports will be a formal table.

3. This rubric represents what students receive for complete laboratory reports. It maps out all expectations, clearly identifying elements related to format.

HPLC Report Grading Rubric

Name______________________________

Statement of Problem (3 Points)			
3 points Purpose and objectives of experiment completely stated combining technique(s) and analyte(s)	2 points Purpose or objectives missing or not stated completely	1 point Too generic to be useful	
Description of Method (7 points)			
7 points All experimental parameters reported, procedure in lab manual referred to and sample information included so that procedure could be repeated	5.5 points Some key information missing from parameters or sample information	4 points Serious omissions from experimental parameters or sample information	
Experimental Results (10 points)			
10 points Results are summarized and presented appropriately in easy to find tables and figures	8 points Results, tables and figures included but poorly organized or presented. Summary does not refer to specific table and figure numbers. Tables and figures do not appear in the order in which they are mentioned	7 points A key component of the results was omitted	6 points Significant omissions from the results tables and/or figures
Analysis and Evaluation (10 points)			
10 points A complete analysis and evaluation of the data has been performed including reporting percent errors with accepted values, identifying positive and/or negative bias and explaining the most likely cause of the bias	8 points Percent errors are reported along with identifying positive and/or negative bias with weak explanation	7 points Agreement with accepted or reported values is mentioned, but no attempt is made to explain why the differences might arise	0-5 points No critical analysis of the results is presented
Calculations (10 points)			
10 points Primary calculations and propagated uncertainties are correct	7 points Primary calculations are correct, but propagated uncertainty appears incorrect or vice versa	5 points Propagated uncertainty has not been considered or has major calculation errors	
Table Formatting (5 points)			
See previous rubric			
Figure Formatting (5 points)			
See previous rubric			