CHAPTER 4

Quantitative Skills

Experimental chemistry relies heavily on quantitative skills and analysis. Successful data collection and analysis in the AP Chemistry laboratory requires many skills, including accurate and precise measurement of various quantities using a wide range of instruments, unit conversions, estimation, algebraic and statistical calculations, and several types of graphing. Quantitative information obtained using these skills must then be integrated with reasoning and higher-order thinking skills in order for students to successfully analyze and interpret data and formulate and communicate conclusions. Information about how this manual supports development and successful application of quantitative skills in the labs is presented here, followed by discussion of some of the most important skills needed in AP Chemistry.

QUANTITATIVE SKILLS IN THIS MANUAL

Students come to AP Chemistry with some quantitative skills developed during earlier course work and experiences. The 16 experiments in this manual provide opportunities for students to practice and improve existing skills and to develop new skills. Each experiment by its nature demands a different combination of skills. The teacher manual for each experiment details the skills students need to successfully complete the experiment in the Skills section. This section is divided into Prior Skills and Developing Skills. The Prior Skills part describes skills used in the lab that most AP Chemistry students have as a result of prior course work, and thus may not require direct instruction or practice before students can apply them successfully. The Developing Skills part details skills, techniques, and equipment that many AP Chemistry students generally have less experience with and mastery of, and thus will likely require either instruction or practice or both before students can use them. After reviewing the Skills section of the lab, teachers should assess their students' existing skills to anticipate and plan for student challenges and questions as they complete the lab, and to identify areas that require instruction beforehand and extra monitoring during the lab.

The labs are designed to promote new skill development and to challenge students to apply skills to solve problems using inquiry; as such, most of the labs contains a Practice component in order to introduce new techniques and equipment and to reinforce fundamental skills before students undertake the Investigation portion of the experiment, in which they apply their quantitative and other skills to address the Central Challenge. The table below provides a brief listing of the major quantitative skills involved in each of the 16 experiments.

KEY QUANTITATIVE SKILLS IN AP® CHEMISTRY LABS

The most important quantitative skills in the AP Chemistry laboratory can be roughly classified into four types: measuring, calculating, creating tables and graphs, and analysis. This classification scheme is useful for discussion purposes; in practice, these skills overlap and in the laboratory setting they must be used in conjunction with each other to accomplish experimental goals. Students will generally already have some skills and abilities in each of these four areas, while they will need to develop others through their work in the AP Chemistry laboratory.

Measuring

Measuring skills consist of using a wide range of tools including rulers, balances, thermometers, timers, and volumetric glassware to make accurate and precise measurements with appropriate significant figures; calibrating and using electronic measuring devices such as pH meters and spectrophotometers; and making decisions about appropriate measuring tools for different tasks. Many students will not have used a buret, volumetric flask, pH meter, or spectrophotometer prior to AP Chemistry. Teachers may need to provide direct instruction about how to use measuring devices the first time students conduct a lab with a particular tool. Teachers can demonstrate a technique themselves or show a short video or simulation. As teachers guide and supervise the lab, they can monitor students' measuring technique and use of significant figures and provide feedback and prompting as needed. Teachers should emphasize the importance of careful measurement often in order to help students realize that sufficient and accurate data is essential in order to solve problems and answer questions. No amount of analysis or calculation can make up for poor data!

Calculating

Most labs require several types of calculations. These include unit conversions, solving for unknowns in algebraic calculations, and statistical calculations such as percent error and standard deviation. Many calculations involve using logarithms and scientific notation. Most of these calculations mirror those required in other parts of the AP Chemistry course, so teachers will find it helpful to discuss connections between content they are studying and calculations they are doing as part of other tasks, like homework problems. For example, an experiment may require students to calculate the percent composition of a substance, a calculation they would also use to solve stoichiometry problems outside of the lab. If, on the other hand, a particular lab addresses content that students have not yet studied in other parts of the course, the teacher may need to model calculations related to the content or provide resources for students to refer to.

While most students have experience with unit conversions, simple algebraic calculations, and scientific notation, many have not performed statistical calculations like percent error that are central to data analysis and interpretation, and direct instruction is called for.

Labs also provide a terrific opportunity for students to use spreadsheets developed in programs such as Microsoft Excel to perform calculations and share data. Facility with spreadsheets is an extremely valuable skill both within and beyond AP Chemistry and it is well worth the instructional time for teachers to demonstrate their use and for students to practice using them. References related to spreadsheets in chemistry are included at the end of this chapter.

Creating Tables and Graphs

Collecting, tracking and organizing data in the laboratory is often facilitated by use of data tables. Learning to construct data tables involves skills such as identifying dependent and independent and control variables, choosing appropriate quantitites and units for measurement, and use of computer programs for word processing or spreadsheet creation. Analysis and presentation of data in the chemistry laboratory often calls for the use of graphs of different types. Generating and using these graphs requires a number of skills including plotting coordinates, determining independent and dependent variables, determining slope, and choosing appropriate scales. Higher-level skills include linear regression or best-fit lines, and determining points of inflection or derivatives; these skills often call for use of a graphing calculator or computer spreadsheet. Using these tools to generate and interpret graphs is not essential, but it is highly desirable because they allow for relatively fast analysis, generally are more accurate and precise, and are more professional in appearance than hand-drawn graphs. Use of spreadsheets for graphing and analysis is also a transferable skill that is useful in many other courses and scientific contexts.

These skills are applied differently in different chemical contexts; titrations call for different types of graphs than kinetics experiments, for example. Thus another needed skill is determining the type of graph that is appropriate for a given situation in the laboratory. As with measuring and calculation skills discussed earlier, students will likely have experience with some of these graphing skills coming in to the course, while others will be new and will require instruction and extra guidance from teachers in order to support successful student development.

Quantitative Analysis

Quantitative analysis is making meaning out of quantitative information generated through measuring, calculating, and graphing. It is often the most difficult part of the quantitative work in the laboratory, but it is essential in order to answer experimental questions successfully. The only way students can develop and strengthen these skills is through practice, practice, and more practice. Three quantitative analysis tasks that are common parts of laboratory work in chemistry are interpreting data, assessing accuracy and precision, and error analysis.

Interpreting Data

Interpreting measured and calculated values in terms of the chemical system under study is something many students find challenging, especially as experiments

and calculations become more sophisticated. A relatively simple example is in the titration lab, where students measure the amount of sodium hydroxide required to titrate different beverages to a phenolphthalein endpoint. Once they make these measurements, they need to analyze the data to determine the relative acidity of the drinks. Students need to make the essential connection that a larger endpoint volume means a more acidic drink in order to answer the central experimental question.

Assessing Accuracy and Precision

Quantitative analysis also encompasses assessing the accuracy and precision of results. Returning to the titration lab example, students need to analyze their endpoint volumes for the same drink to determine if they are sufficiently close together or precise enough. They need to determine if any of their endpoint volumes are outliers that should be discarded. Students must make a decision about how many samples of each drink to titrate. All of these decisions require analysis of precision and accuracy. Teachers should ensure that students understand standard deviation is a measure of precision and percent error is a measure of accuracy, and that repetition makes for more robust data that enhances the chemist's ability to draw conclusions and answer questions. Teachers may choose to delve further into statistical analysis with students, addressing topics such as confidence intervals and p-values, if desired. Knowing how to use statistics to analyze the quality of laboratory results is extremely important in higher-level courses and an introduction to these concepts will thus benefit students.

Error Analysis

A third quantitative analysis task is error analysis, which involves assessing likely sources of error and their affects on measured and calculated values. Returning to the titration lab, students often titrate samples beyond the endpoint, causing their calculated values of the acid concentration of the sample to be higher than they actually are. Recognizing this connection between the error in technique and the impact on the calculations is an important component of drawing meaningful conclusions about the drinks' acidity and experimental error.

WEB RESOURCES

- Tutorial on graphing calculators
  http://dwb.unl.edu/calculators/chem-math.html
- "Introduction to Statistics in Chemistry":
  http://chemlab.truman.edu/dataanalysis/statistics_files/statisticsfundamentals.htm
- Tutorial on the use of Excel in chemistry:
  http://www.wellesley.edu/Chemistry/stats/form1.html

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