Technology Standards and the Chemistry Laboratory

by Loretta Jones and Seán P. Madden

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If we were to imagine an ideal high school chemistry classroom, we might envision students doing inquiry-based, hands-on activities and using technology to enhance their learning. Yet, in actual classrooms, laboratory activities can be time consuming, expensive, and are sometimes overlooked, despite their importance. The standards for learning about technology and for laboratory instruction are broad and allow for a variety of interpretations. In general, inquiry experiences, many of which involve hands-on work with chemicals, are recommended (see chapter 4). However, even simple investigations can inspire and enlighten students. Questions such as how much time should be allotted for laboratory work, what a properly equipped laboratory should contain, and what types of laboratory activities are the most important, are left open to interpretation by individual teachers and school districts. In this chapter, we summarize current thinking about how to provide students with good laboratory experiences and share a variety of ways in which teachers can enrich classroom instruction with technology.

Laboratory Learning

The high school chemistry teacher is typically faced with limited resources and time; it is difficult under these conditions to conduct an exemplary laboratory program. Fortunately, help is available. The American Chemical Society (ACS, 2003) has produced a booklet on chemistry teacher preparation that also includes guidelines for managing laboratory work. In addition, the National Science Teachers Association (NSTA) has developed a set of guidelines for ideal high school science laboratories (Biehle et al., 1999). However, simple, low-cost and small-scale equipment, which has the advantage of reducing hazards and the amount of waste produced, can be used to introduce students to scientific inquiry and basic laboratory skills in nearly any classroom (Waterman and Thompson, 2000; Towse and Huseth, 1997; also see http://ssc.mriresearch.org).

In any kind of hands-on activity, safety is a primary concern. The ACS booklet on teacher preparation provides basic information on producing a safe environment in the high school chemistry laboratory (Tinnesand, 2007). Another useful resource for high school chemistry teachers is the Flinn Scientific catalog, which provides comprehensive information on how to store chemicals safely (Flinn, 2007). In addition, the NSTA has published a safety handbook for high school teachers that provides guidelines for working safely with chemicals (Texley, 2004). Green chemistry activities also offer options to improve safety and reduce waste, given their emphasis on the use of nontoxic, environmentally friendly methods, and chemicals (La Merrill et al., 2003).

Table 1. Science and Technology Standards

Grades 9–12
Abilities of technological design Understanding about science and technology

Source: NRC, 1996, p. 107.

Table 2. Changing emphasis on technology and laboratory as a result of NSES

Less of this	More of this
Purely paper-and-pencil or drill-and-practice exercises for numerical problem solving	Regular use of computers and graphing calculators to enhance quantitative understanding of chemistry
Spending an entire laboratory session simply setting up equipment and gathering data	Regular use of computer and graphing calculator interfaces with data collecting instruments that allow simultaneous data analysis and interpretation
Viewing data collection and graph making as an end in itself	Discussing the meaning of data and graphs, and connecting them to molecular phenomena
Use of outdated and unsafe practices that may lead to injury	Consistent use of appropriate safety procedures in all laboratory and demonstration settings
Conveying the behavior of chemical systems at the molecular level only with words	Using animations and molecular modeling software to facilitate visualization of molecular-level phenomena
Learning and teaching only with text	Multimedia animations to enhance conceptual understanding of chemistry and to provide additional inquiry experiences

Laboratory and Technology in the National Science Education Standards

The *National Science Education Standards* (NSES) for science and technology are very brief (Table 1), yet employing technology in the classroom and laboratory can significantly enhance student learning (Table 2). When computers or graphing calculators are used in the laboratory, data can be interpreted immediately and may therefore be more meaningful to students. Computers also allow teachers to introduce their students to molecular visualizations so that they can build more accurate mental models of the particulate level of matter (Kelly and Jones, 2007).

Technology in the Laboratory

Microcomputer-interfaced laboratory experiments make the introductory chemistry laboratory a new experience for students (and teachers, too!). Instead of repeating the same experiments that were completed by students a generation ago, today's students can have access to equipment that will collect data in a shorter period of time and present it in a more meaningful format. The emphasis of the laboratory experience can then shift to learning the concepts underlying the measurements, rather than on tedious weekly repetition.

Computer technology affords students of the 21st century a powerful opportunity to understand the intimate connection between science and mathematics. *Mathematical* models, (executed by computers) complement *chemical* models (which seek to bridge our macroscopic observations with their underlying microscopic, molecular basis). Inexpensive graphing calculators and the data collection devices that interface with them are the ideal computer technology for use in K–12 school setting.

Graphing calculators, such as those manufactured by Texas Instruments, Casio, Hewlett Packard, and Sharp, have the following capabilities:

- Spreadsheet features in which data can be stored, graphed in a variety of formats (such as scatterplots), and transformed into using built-in mathematical functions like multiplication by a constant, inverses, logarithms, etc.;
- Regression functions, such as polynomial, sine, and logistic equations to analyze data or scatterplots of these data;
- Equation editors in which students can build their own mathematical functions to model the data contained in the list feature. Equation editors allow a function to be graphed, traced, solved for roots/maxima/minima, integrated numerically, and to have derivatives determined at specific points along the curve;
- Matrix algebra operations that allow for multiple linear regression of a data set, simultaneous solution of systems of equations, and other statistical treatments of data beyond the built-in capabilities of a calculator;
- Interfaces with data collection instruments, such as those manufactured by Vernier (Texas Instruments and Casio lines of calculators); and
- Programmability, allowing the user to design software that, among other things, controls the sample rate of an instrument and the display format of the collected data.
- All of this computing power comes in the form of an inexpensive hand-held device. Thus, graphing calculators fulfill much of the promise of our computer age and seem also to be the ideal choice of computer technology for the K–12 classroom.

An activity commonly carried out in the high school chemistry classroom and demonstrating many of these points can be found in Fig. 1. One of the goals of such a laboratory activity is that students discover an appreciation for the connection between the macroscopic phenomenon

Figure 1. Titration Experiment: A Traditional Approach

Suppose a group of students were titrating 50.00 ml of a weak acid (0.1000 M acetic acid), with 0.1000M NaOH. Without access to graphing calculators or a computer, students would titrate to an endpoint and collect only one data point for the titration. Students can connect their data to a stoichiometric calculation but will not see how the pH changes during the titration.

of pH and the microscopic, molecular behavior of the chemical species involved in the equilibrium reaction. Another goal is that students will discover the power of a mathematical model, in this case, the equilibrium constant, to connect these macroscopic and microscopic realms. Fig. 2 describes how the graphing calculator can serve as a great teaching and learning tool in this situation.

This same theme of collecting data and generating mathematical models to explain the data can be applied throughout the chemistry curriculum. When graphing calculators and their associated data collection devices are made available in the classroom, many opportunities arise for exploring the connections between mathematics and science, which further illuminate the connection between macroscopic and microscopic dimensions of chemistry.

A variety of resources are available to teachers who want to incorporate graphing calculator and data-gathering technology into their chemistry classrooms. These resources can be found in publications such as the *Journal of Chemical Education* and from publishers of high school mathematics curricula and chemistry curricula. Vendors of these materials include Vernier, Texas Instruments, Casio and Ocean Optics, Inc. Vendors' philosophies about their own technology range from those who seek to provide teachers and students with painless, black box data gathering and analysis tools, to those who seek to teach chemistry and science through activities that encourage students and teachers to develop their own ideas, including writing their own software programs.

Figure 2. Titrations Redux: Taking Advantage of Technology Approach

With a Vernier pH probe connected to the data collector of a graphing calculator, students would be able to collect data such as that in Table 3 (reproduced from Skoog et al., *Analytical Chemistry,* 7th edition, 1996, p. 212, a college text, which contains a table of data for this common high school activity). Students enter the data into the spreadsheet feature of the calculator as shown in Fig. 3. (Note: Although the screen shots shown here are from the CFX-Casio 9850 GB Plus, the displays of Texas Instruments, Hewlett Packard, and Sharp calculators are very similar). Data are displayed using a view window (Fig. 4), and as a scatterplot shown in Fig. 5. (By default, the graphing calculator leaves the axes unlabeled; however, *x*- and *y*-axis labels such as "pH" for the *y*-axis and "volume of titrant" for the *x*-axis can be easily added.)

The curved appearance of the data might come as a surprise or discrepant event to the novice high school student. A guided inquiry discussion (see chapter 4) can lead to the following form of the Henderson-Hasselbalch equation, which describes the equilibrium behavior of weak acid systems:

$$pH = pK_a + \log [A^-]/[HA].$$

This equation can then be modified and entered into the equation editor (Fig. 6) of the calculator:

$$Y1 = 4.7 + \log (X \div (50 - X)),$$

where Y1 represents pH over the course of the titration, $pK_a = 4.7$ for acetic acid, X represents the variable concentration of acetate ion during the titration, and 50 represents the analytical millimoles of acetic acid present per liter. Graphed on the same view window as the data, students may be pleasantly surprised to find a similarly shaped curve (Fig. 7).

When the theoretical curve is superimposed on the raw data, students will undoubtedly notice a satisfying agreement with the mathematical model (Fig. 8). They may want to perform "mathematical experiments" to find another section of curve that matches the data for the remainder of the titration. Or, they may want to trace along the curve with the derivative feature in order to gain a sense of how quickly pH changes at different times during the titration (Fig. 9).

Technology for Conceptual Learning

Technology can be used to not only support and enhance laboratory instruction, but also to enhance the learning of chemistry concepts both in the classroom and during homework. Modern chemistry and biology focus on the structure and properties of molecules. Molecular visualization programs enable scientists to create and manipulate dynamic representations of molecular structures that are otherwise hard to visualize. Such software can radically change the introductory chemistry curriculum by allowing a much earlier, and more central, focus on molecular structure and properties. Visualization programs make abstract chemical concepts more real and meaningful to students. However, students must develop those visualization skills. Meaningful, independent use of these tools by students requires guidance. For example, the *Chemsense* program, which allows students to build and animate molecular structures, provides orientation information for teachers and guidance for students (SRI, 2005). The *ChemDiscovery* program, which is a comprehensive one-year chemistry course on computer, offers extensive support materials for teachers (Agapova et al., 2000).

Virtual laboratories that make use of multimedia software allow students to view chemical reactions too hazardous to view in person. They can also promote rapid transfer of learning to the actual situation and allow the experiments used in the laboratory to be upgraded. The combination of hands-on and virtual labs makes it possible to *increase* the amount of skills training, without increasing the time spent in lab. For example, in one school, time constraints did not allow students to perform dilutions in lab using volumetric glassware nor to prepare their own calibration curves for instruments. When multimedia software was introduced, it became possible to develop new hands-on experiments that required students to make several dilutions and to construct a calibration curve (Jones and Smith, 1991).

The computer simulations in virtual laboratories make many more reactions accessible to students and permit repeated trials, certainly more than would be possible in a hands-on laboratory. Simulations permit students to work with systems not possible to include in the laboratory, such as explosive mixtures, toxic chemicals, and reactions carried out at remote sites. Furthermore, because the experimental observations can be immediately interpreted and analyzed with the aid of the computer program, content learning can be enhanced beyond what is possible with traditional methods. Good sources of reviewed and freely available computer-based instructional materials include Multimedia Educational Resources for Learning and Online Teaching (Merlot, 2007) and a free interactive online introductory chemistry textbook (Rogers et al., 2007). It is important to note that these simulations should be used to *enhance* instruction, not to replace it. The benefits of inquiry-based hands-on activities cannot all be replicated in a computer program.

Table 3. Data collected from a titration of 50.00 mL of 0.1000 M CH_3COOH, a weak acid, with 0.1000 M NaOH

Volume of NaOH (in mL)	pH
0.00	2.88
10.00	4.16
25.00	4.76
40.00	5.36
49.00	6.45
49.90	6.7.46
50.00	8.73
50.10	10.00
51.00	11.00
60.00	11.96
75.00	12.30

Source: Skoog et al., 1996, p 212. Reprinted with permission from *Fundamentals of Analytical Chemistry*,7E © 1996 Brooks/Cole, a part of Cengage Learning, Inc.

Figure 3

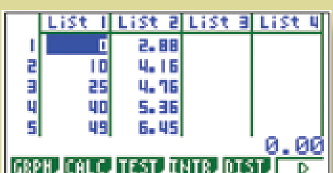


Figure 4

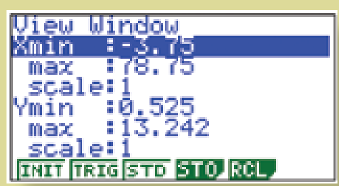


Figure 5

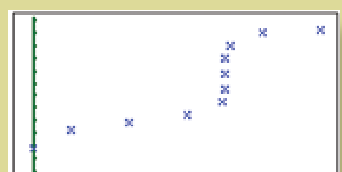


Figure 6

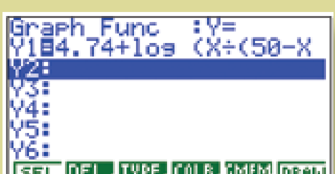


Figure 7

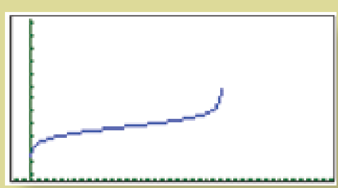


Figure 8

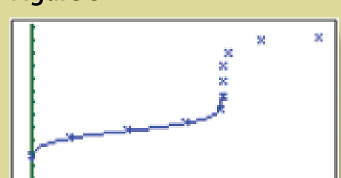
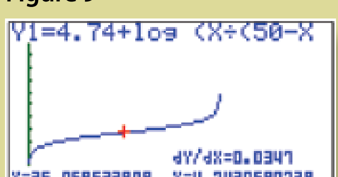


Figure 9



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Recommended Web Sites

Casio. http://casioeducation.com. (This Web site contains an archive of graphing calculator activities written by teachers that can be used in conjunction with all types of Casio graphing calculators) Merlot. http://chemistry.merlot.org (accessed July 13, 2007).

National Council of Teachers of Mathematics. http://www.nctm.org. The NCTM publishes several peer-reviewed journals. The *Mathematics Teacher* often contains articles demonstrating how graphing calculator technology and laboratory data can be incorporated into the classroom.

Ocean Optics. http://www.oceanoptics.com. This company manufactures and markets a number of data gathering instruments that can be interfaced with graphing calculators and computers.

SRI (2005). http://www.chemsense.org/ (accessed March 22, 2007).

Texas Instruments. http://www.ticares.com. (This Web site contains an archive of graphing calculator activities written by teachers that can be used in conjunction with all types of Texas Instruments graphing calculators).

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