CONCEPT BUILDING THROUGH ACTIVE LEARNING EXPERIENCES WITH THE CALCULATOR BASED LABORATORY (CBL)

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Introduction

The graphing calculator coupled with physical or chemical sensors is known as the Calculator Based Laboratory (CBL) and has proven to be an excellent tool for developing concrete experiences in science and math courses [1,2,3]. The CBL offers several benefits:

- Fast data acquisition and robust statistical tools for data processing;
- Flexible implementation—that is, measurements do not need to be restricted to a conventional laboratory; it can be used in a classroom, in the field, or even at home;
- A good motivation factor—students' attitudes are often positively influenced by the fact that they can handle the relatively sophisticated measurements that are possible with the available sensors.

With the CBL, it is possible to generate and process data in a convenient time frame within the laboratory or even the classroom set-up. The design of activities can be focused on understanding relationships between variables, building empirical models derived from those relationships, and bringing together generalizations. In this sense, the proper use of the CBL is consonant with active learning environments: student-centered activities whereby the use of incisive inquiry by the teacher replaces plain lecturing, and ideally, conceptual understanding takes the place of algorithmic thinking [4].

During recent years, we have been working with the design of active learning activities using the CBL for various groups such as high school teachers, pre-service science education students, and natural science students. The format of a typical CBL activity integrates the following stages:

- **Background**–Give the students the necessary information to make the most of the pedagogical objectives. It also helps in laying a minimum common knowledge base to facilitate an effective use of questions during the course of the activity.

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- **Data Acquisition/Processing**–Provide a set of instructions as to how to operate the CBL to perform a given task. This is the stage where students follow directions to acquire familiarity with the procedures. Processing of the data may follow immediately or can be done after the discussion of initial results.
- **Analysis of Results/Synthesis**–At this stage, a set of questions is used to guide a discussion with the objective of extracting meaningful information from the results. This is the center of gravity of the whole activity, thus its design requires the greatest care and attention to every detail. Every single question represents a deliberate effort to stimulate students to think analytically—recognizing and interpreting patterns, relating factual information to observed data, and integrating results in the form of generalizations [5,6].
- **Application**–At this stage, students are faced with a hypothetical situation where the acquired knowledge can be applied. This stage is multifold: it helps the teacher to evaluate student level of understanding, and also helps students to self-evaluate the conceptual insight gained from the activity.

Variations from the suggested format are conceivable considering that the activity's objective will define the relative emphasis of each stage [7].

Among several chemistry activities we have developed, including the use of sensors for measurements such as pH, absorbance, and conductivity, a description of one of those activities is presented here to illustrate the implementation of the four-stage format.

An Example of a CBL Activity – "Acid and Bases: Beyond Chemical Antonyms"

The purpose of this activity is to discover an empirical relationship between solution pH and solute concentration. From such a relationship, an operational definition of a weak and strong acid and base is obtained.

1. Background Stage

At the beginning, the *general* objective of the activity is presented; that is, to study the relationship between the pH and the concentration of a given solute in solution (C_s). The following concepts are reviewed:

- Logarithms
- pH
- Concentration
- Solution/solute/solvent
- Dilute/Concentrated Solution
- Hydrogen ion concentration ($[H^+]$) in water
- Neutral/acid/alkaline solutions

It should be pointed out that a critical distinction must be made between the objective of the study (pH as a function of C_s) and the general definition of pH = - $\log[H^+]$, where $[H^+]$ stands for H^+ concentration.

2. Data Acquisition and Processing Stage

Several groups of students do measurements of pH of four solutions. We propose that the substances used in the activity be among those found in household products. See Table 1.

Table 1. Solutions used in the Study of pH as function of solute concentration.

Substance	**Chemical Nature**	**Source**
Ammonia	Weak Base	Glass Cleaner (Windex®)
Acetic Acid	Weak Acid	White Vinegar
Sodium Hydroxide	Strong Base	Sink Cleaner (Drano®)
Hydrochloric Acid	Strong Acid	Muriatic Acid (pool acid)

Each group of students does at least one pH measurement on each of the six solutions of a given substance of varying concentration (a total of six measurements). Students do not know the identity of the solutions, just their concentrations. The time needed is about thirty minutes.

Typical results obtained on the graphing calculator are shown in Figure 1.

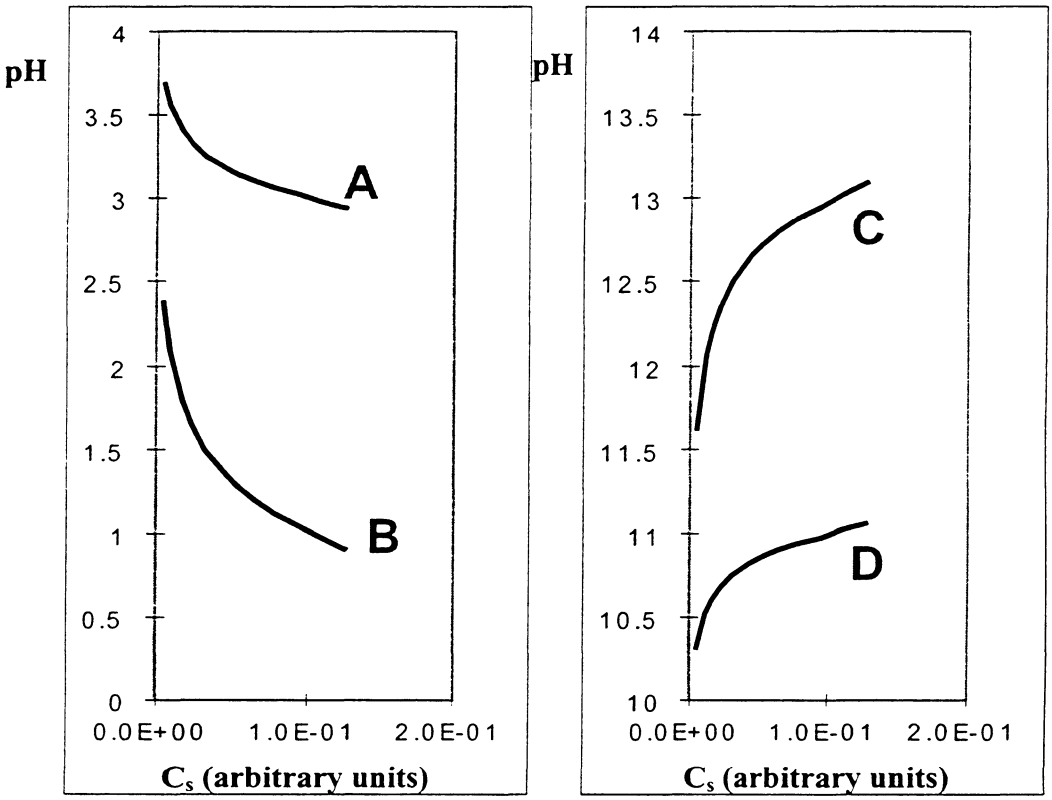


Figure 1. Plots of pH as a function of solute concentration. A: Vinegar; B: Hydrochloric Acid; C: Sodium Hydroxide; D: Glass Cleaner (Windex®).

The observed trends of pH vs. concentration are discussed, and students compare them with graphical representations of known functions such as the logarithmic, linear, and exponential functions. Further discussions lead to the validity of data processing for its linear transformation as shown in Figure 2.

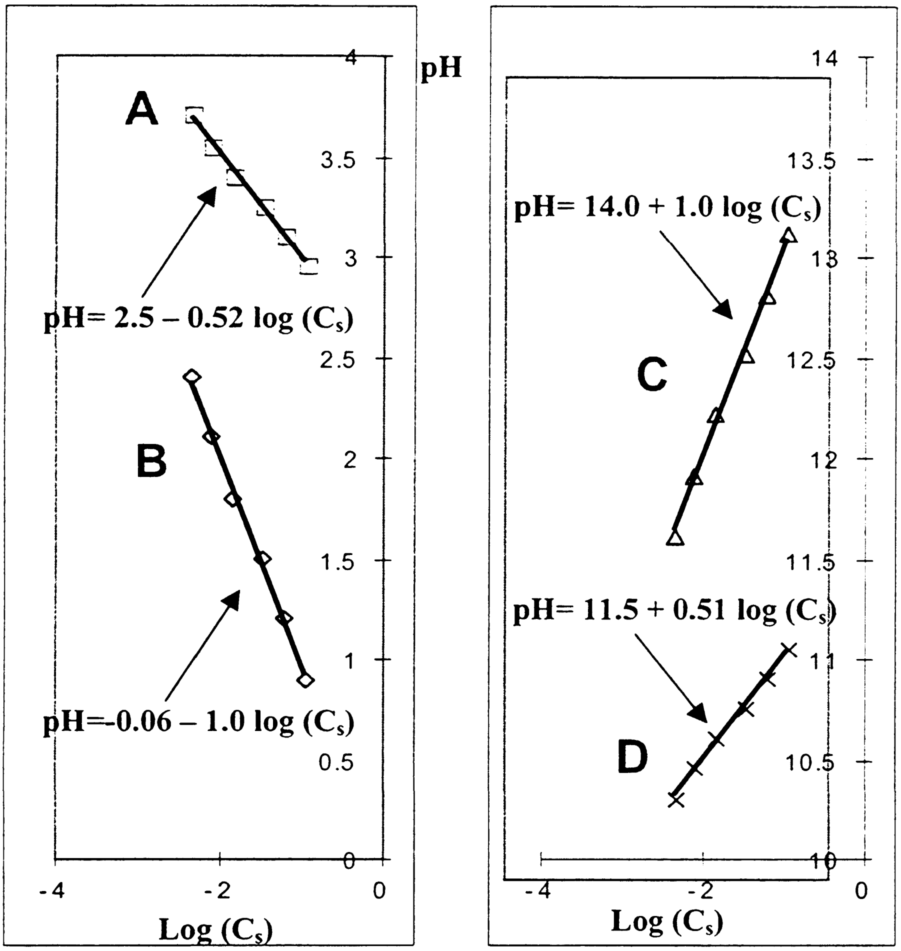


Figure 2. Plots of pH as a function of common logarithm of solute concentration. A: Vinegar; B: Hydrochloric Acid; C: Sodium Hydroxide; D: Glass Cleaner (Windex®).

Linear regression of the data points confirm the correlation between variables (with correlation coefficients greater than 0.98).

3. Data Analysis/ Synthesis Stage

The processed data present four straight lines suggesting a general model of the form:

$$pH = b + m \log C_s \qquad (1)$$

where b and m represent parameters commonly known as the y-intercept and slope of the regression line (here the independent variable = log C_s).

By looking at the slopes of the lines, an interesting pattern is observed: the slope can take on the following values close to either ± 0.5 or ± 1. In other words, the rate of change of pH as a function of the logarithm of solute concentration is either positive or negative and may either be close to 0.5 or 1.

At this point, students are asked to relate this finding to the chemistry of the system. Some students figure out that the observed trends have something to do with the acid/base properties of the solutions. For others, the distinct trends suggest that two interrelated properties define the behavior of the system. From this basis, we can come up with an operational definition of an acid and a base: the two apparent properties are the acid/base *behavior* of the solution and its acid-base *strength*. The slope sign indicates if the substance is an acid (-) or a base (+), while the slope magnitude is related to strength: 0.5 for a weak, 1 for a strong acid or base.

Notice how this simple experiment helps to characterize acid/base behavior as a result of the relationship between two variables; so that, knowledge of how pH varies with concentration leads to a decision about whether a substance is acidic or basic, and whether it is strong or weak.

Another important corollary of this activity is its integration to some math concepts. Part of the activity's discussion is devoted to finding a direct relationship between $[H^+]$ and C_s. Knowing that pH= - log $[H^+]$, the mathematical interpretation of the slope of the pH vs. log C_s graph is given by the third column in Table 2:

Table 2. Mathematical Interpretation of the Slope in Equation 2 in terms of $[H^+]$ vs C_s

Chemical Nature	**Slope**	**Relationship between C_H+ and C_s**
Strong Acid	-1	$[H^+]$ is directly proportional to C_s
Strong Base	+1	$[H^+]$ is inversely proportional to C_s
Weak Acid	-0.5	$[H^+]$ is directly proportional to the square root of C_s
Weak Base	+0.5	$[H^+]$ is inversely proportional to the square root of C_s

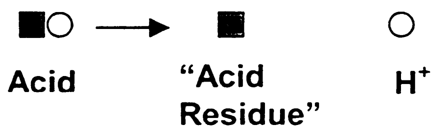
4. Application Stage

After studying and understanding how the nature of a given acid or base solute affects the pH of its solution, the student is faced with a hypothetical situation where the acquired knowledge needs to be applied. An example of such an exercise is:

> On the bench, there are two solutions (A and B) both exhibiting the same pH= 3.8. Both solutions are then diluted by the same factor, but the diluted solution A exhibits a pH= 4.3 and the diluted solution B has a pH= 4.8.
>
> Questions:
>
> Based on the acquired knowledge,
>
> 1. What is the nature and strength of solution A and B ?
> 2. How does the concentration of A and B compare?

Interestingly, students have trouble with those questions (specifically, determining the relative strength and concentration of both solutes). Even after going through this activity, some students (especially those with some background on the subject!) do not correctly identify the two solutions. One reason for the observed flaw is that students usually base their answer on the absolute value of pH at any given instance. They reason that the lower the pH of an acidic solution, the stronger the acid, obviously neglecting the effect of solute concentration. Solution B should be the strong acid because of its greater rate of pH change as the concentration of this solution is changed. On the other hand, solution A should be the more concentrated, since being a weak base it exhibits the same pH as the solution of a strong acid.

The discussion of this application provides the opportunity to clarify student understanding of acid/base solutions. It is possible to take advantage of the self-acquaintance the application produces and put the concepts in the right perspective. This application can be illustrated using an analogy that has elements of the student's previous knowledge. The most elementary definition of an acid is usually that it is a species capable of donating H^+. In that sense, an acid may be depicted as follows:



From the analysis of the results obtained in the activity, we concluded that $[H^+]$ is proportional to the concentration of a **strong acid** (Table 2) while it is proportional to the square root of the concentration of a **weak acid**. The problem states that solutions A and B initially have the same pH (same H^+ concentration) but after dilution, the pH of A is lower than the pH of B (H^+ concentration in A is greater than H^+ concentration in B). A pictorial presentation of those findings could be:

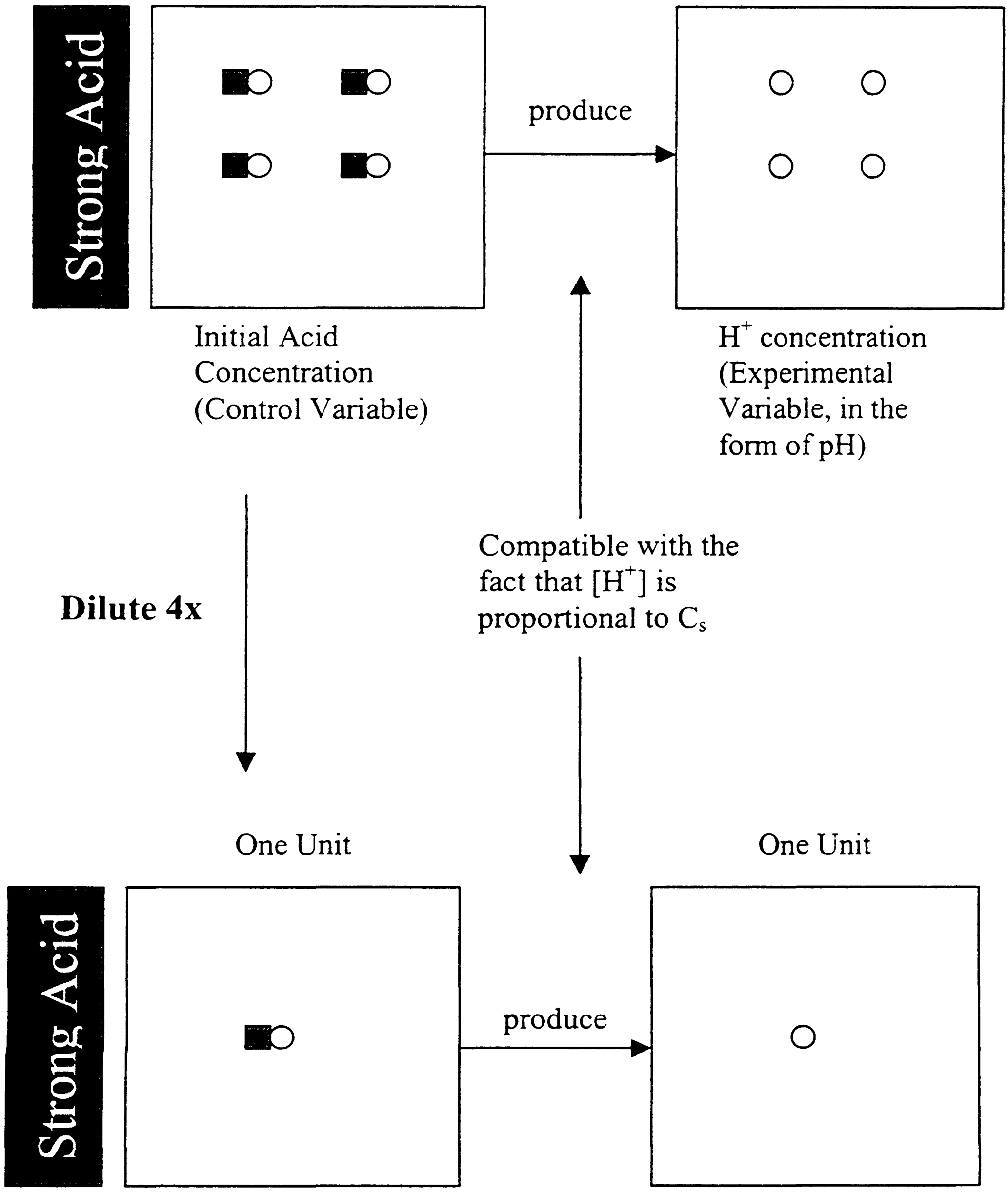


Figure 3a. Microscopic view of the dilution of a strong acid and its effect on H^+ concentration.

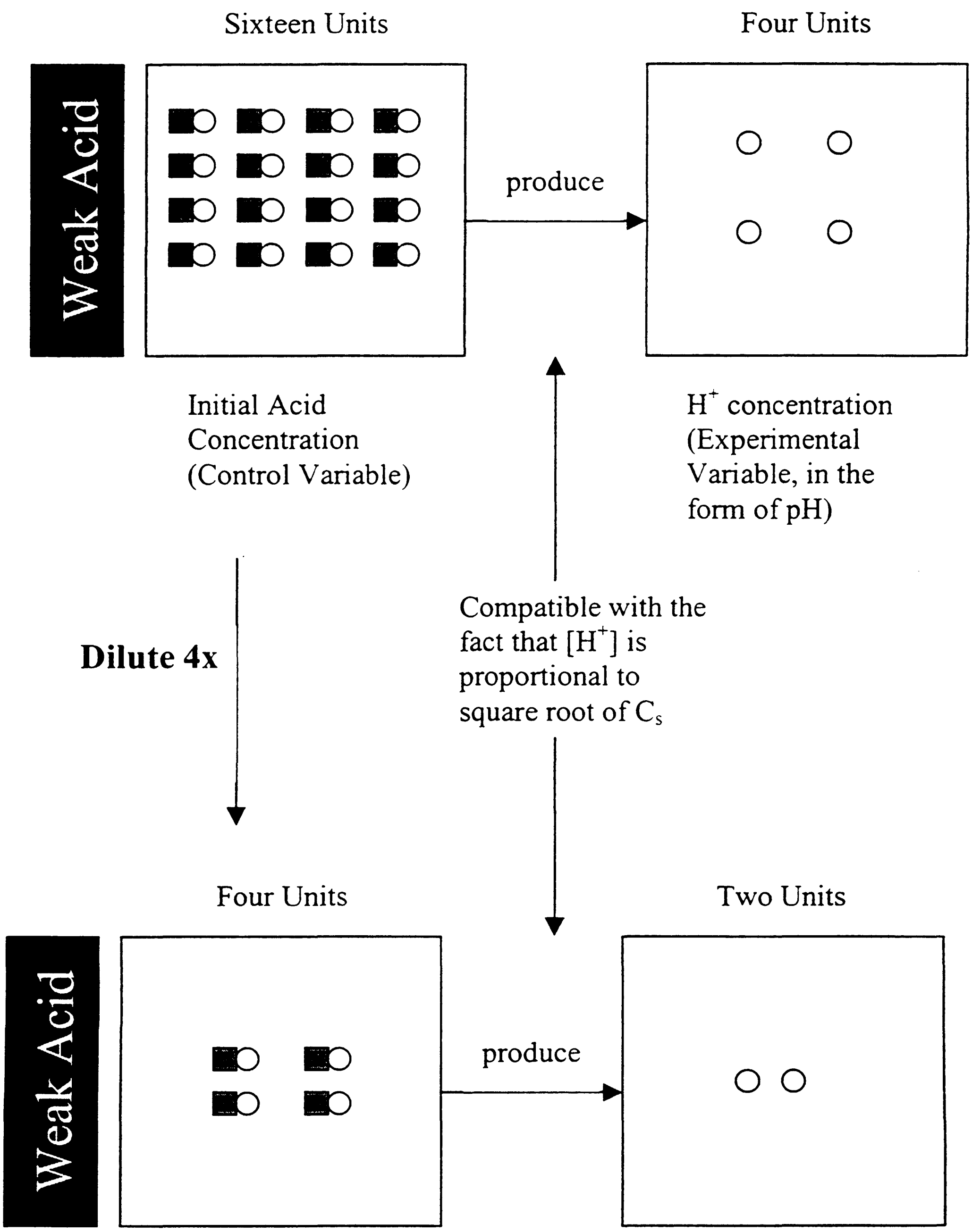


Figure 3b. Microscopic view of the dilution of a weak acid and its effect on H^+ concentration.

Figure 3a illustrates the change in $[H^+]$ when a strong acid is diluted. Considering a fixed volume at all times, the initial concentration of acid "produces" an equal concentration of H^+ (four units). A solution of the same acid diluted by a factor of four is accompanied by a four-fold decrease in $[H^+]$. This is consistent with the finding establishing that $[H^+]$ is directly proportional to C_s for a strong acid.

Figure 3b illustrates the change in $[H^+]$ when a weak acid is diluted. Again, considering a fixed volume, this time the initial concentration of acid produces $[H^+]$ equivalent to the square root of C_s. A solution of the same acid diluted by a factor of four is accompanied by a two-fold decrease in $[H^+]$. This is consistent with the finding establishing that C_{H^+} is directly proportional to the square root of C_s for a weak acid. Even though the original $[H^+]$ in both solutions (Figs. 3a and 3b) were the same, both the difference in the nature and in the concentration of the acids involved, participate in generating the difference in H^+ concentrations after dilution.

Conclusion

Opponents of the implementation of inductive-thinking oriented activities in the classroom often claim that there is always a risk involved in carrying out an activity that consumes "valuable time" from covering course topics without assurance that this process translates into a deeper understanding of fundamental concepts. This article hopes to make the case that judicious use of the CBL facilitates the creation of effective learning environments for relating quantitative relationships with chemical concepts. The traditional classroom usually provides experiences in developing concepts from a deductive standpoint: general principles are presented, then they are applied to specific situations. The constructive classroom approach relies on an inductive thinking pattern: the study of phenomena in a particular context leads to generalizations and conceptualization. The convergence of both approaches should add a new dimension to the level of conceptual understanding.

Usually the relationships between pH and concentration are theoretically derived by defining the properties of those systems in the microscopic context. In the activity presented here, the relationship between variables is studied in a given chemical system and then a general interpretation is derived from recognizable patterns in the processed data. From this type of experience, the students realize the importance of mathematical models to describe physical or chemical phenomena as well as understand that fixed numerical values in those models may have physical or chemical meaning.

With the wide variety of available sensors and the CBL fast acquisition and robust statistical capabilities for data processing, it is plausible to design activities focusing more on data analysis and its meaning. It must be pointed out, however, that neither the CBL by itself nor the results obtained with it equate to active learning. In designing a CBL activity, attention to the way in which questioning and inquiry will lead to genuine knowledge is the critical issue, since those elements establish the conditions of what an active learning environment is all about. ■

Bio

Noel Motta is Associate Professor in the Department of Chemistry at the University of Puerto Rico, Río Piedras. His main interests are the use of computer-based modules for enhancing problem solving skills in general chemistry, and the development of evaluation instruments to assess scientific reasoning skills in the context of analytical chemistry.

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