A Web-Based Molecular-Level Inquiry Laboratory Activity

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Abstract: This paper presents a new computer-based atomic level simulation of an ideal gas. The simulation is written in Java and is accessed by students through a Web browser. This software is used in conjunction with a written laboratory experiment developed within the framework of an inquiry instructional strategy. This molecular-level laboratory experiment is used in combination with a parallel macroscopic laboratory experiment. We hypothesize that students exposed to these kinds of parallel activities will be better able to link the macroscopic, microscopic, and symbolic understanding of chemical concepts.

[§]Introduction

Molecular Laboratory Experiments (MoLE) in Chemistry are a collection of computer-based simulations of molecular laboratory experiments that can be integrated and linked with parallel hands-on laboratory experiments used in introductory chemistry.

We are developing eight computer-based simulations around the content areas of gas laws, gas-phase equilibrium, kinetics, atomic structure and periodicity, acid–base chemistry, calorimetry, electrochemistry, and molecular and solid-state structure. At the present time, a beta version of the gas laws simulation has been completed and the gas-phase equilibrium simulation is under development. Each MoLE simulation will be a powerful, interactive, dynamic computer simulation, and will be accompanied by guided- and open-inquiry laboratory activities. The materials will help students link the macroscopic, microscopic, and symbolic worlds together and allow them to develop a deeper understanding of chemical phenomena.

MoLE simulations will have the following features:

- a particulate-(microscopic-)level window, a symbolic window, and a macroscopic window that are linked, working simultaneously with each other, so an action can be seen in all the windows;
- a guided- or open-inquiry laboratory manual that will guide and focus student interaction with the simulation and that is parallel (if possible) with a macroscopic hands-on inquiry laboratory;
- software that can be used to explore different questions;
- software that can be used in different instructional settings (lecture; homework; computer laboratory, group or individual activities, exploration; or application phases of instruction);
- a minimalist approach to screen use, user-friendly and intuitive;
- accessibility, using Web-browser software that is platform independent.

The inquiry-oriented instructional approaches used in this project have been shown to have advantages over traditional instructional approaches in attitudes, motivation, and concept and process learning. The key to this instructional approach is that the learner derives the concept from observations of the behavior of a chemical system. One of the weaknesses of laboratory-based instruction is the difficulty of inventing a molecular explanation from laboratory data to justify experimental patterns. Students can observe pressure, volume, and temperature relationships in gases, but they cannot observe the molecular behavior that explains these relationships. The instructor is left with the task of just telling the student about molecular behavior and hoping they will make the macroscopic to microscopic link.

A possible approach that could be used in this project would be to have the student experience the laboratory relationships in a hands-on experiment and then do a parallel experiment on the molecular level using a MoLE simulation. At that point, a concept invention on both the experimental and molecular levels would facilitate the linking of macroscopic and microscopic behavior.

Macroscopic Gas-Law Laboratory

A macroscopic guided-inquiry experiment on gas laws might have the student investigate the relationship between pressure and volume using a syringe and a pressure transducer. In a second experiment the students might investigate the relationship between pressure and temperature. Students would collect data, look for patterns, and invent a mathematical relationship between the variables. Finally, students might do a self-selected open-inquiry experiment to expand their knowledge of gas laws.

Gas-Laws Simulation

This MoLE simulation was developed using funds provided by the graduate college at the University of Oklahoma. The simulation has a particulate-(microscopic-)level window called the gas-sample region that shows particles in constant, rapid, straight-line motion. The particles have different speeds and

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undergo elastic collisions with themselves and the walls of the container. One of the gas particles can be marked to allow students to trace its path and measure its speed. A second window, the control-bar region, allows users to vary the amounts of two different types of particles (He and Ne). This region also allows the user to macroscopically control the pressure, volume, and temperature of the gas sample with coordinated changes in the microscopic window. The symbolic features of the simulation allow users to view dynamic plots of relationships between variables and view a two-dimensional Boltzmann distribution of the particle speeds.

A companion laboratory activity was written to guide the user to develop gas-law concepts. The activity was written to parallel the activities of the macroscopic gas-law experiments in the Abraham and Pavelich *Inquiries into Chemistry* laboratory manual (Waveland Press).

The activities in the macroscopic laboratory and in the simulation have both guided- and open-inquiry activities based on the learning-cycle approach. The companion laboratory-activity write-up for the gas-laws MoLE simulation can be found as an Adobe Acrobat document at http://intro.chem.okstate.edu/2001ACS/MicroGasLaw.pdf. The simulation can be viewed using Internet Explorer at http://intro.chem.okstate.edu/1314F00/Laboratory/GLP.htm.

A number of different questions can be answered by changing the variables that affect the gas and by observing, in real time, how the change affects the behavior of the gas particles. The simulation allows a qualitative view of what happens (watching the behavior of the particles) as well as a quantitative view by watching how the measured pressure changes when either the temperature, moles of particles, or volume of the gas is changed.

A series of experiments can be performed with the simulation to develop a view of pressure and its dependence on collisions with the walls of the container, distance traveled between collisions with the wall, and the intensity (force) of a collision. Other options available include a data-collection feature. In this option students can change an independent variable and observe how a dependent variable is affected. These data can be plotted to provide students with a symbolic view of an ideal gas, driving home the direct and inverse relationship of the variables.

This software is written in Java to allow for speed of interactivity and to allow the software to run on both a Macintosh and PC over the Web.

These materials were tested with a first-semester general chemistry class taught during the summer 2000 term. After all of the students had completed the macroscopic laboratory activity, they were given a Web site address and told to download the laboratory write-up for the microscopic activity. If they turned in the completed laboratory report they would receive extra credit points. Twenty-five of the thirty-five students in the section completed the assignment. The group of students who had completed the simulation activity received an average score of 60% on the examination on gas-law behavior given by the instructor of the course who was not associated with the project. The other ten students had an average score of 48%. Because the experimental group was self-selected, the scores of these two groups on an unrelated unit of material were obtained. On the unit test that preceded the gas-law unit, the average scores of the two groups were 67% and 63%. Although the small size of the experimental and reference group would council caution in interpreting these results, this outcome appears promising.

A close reading of the student responses to the questions in the laboratory write-up led to several observations. First of all, 20 of the 25 students showed direct evidence of linking the microscopic to the macroscopic levels of understanding. Secondly, several misconceptions concerning the behavior of gases at the microscopic level were exposed. Thirteen of the twenty-five expressed a belief that as the volume of a gas decreased the particles increased in speed, and that is what explains the increase in pressure. Modifications in the laboratory write-up will be tested this summer to address that misconception. Two other minor misconceptions were also revealed: collisions between molecules contribute to pressure and a collision with container walls causes particles to slow down. Once aware of these or other misconceptions, the instructor can design activities that will help address them (e.g., the instructor can ask students to use the software to prove or disprove the following assertion: "Particles slow down when they collide with the container walls."). This approach is possible because of the flexible nature of the software and is consistent with the research on conceptual change.

The gas law simulation was invited to be submitted for peer review through MERLOT (Multimedia Educational Resource for Learning and Online Teaching), http://merlot.csuchico.edu/Home.po, a Web-based facility for the dissemination and evaluation of computer-based curriculum materials, sponsored by a consortium of universities.

We see the gas-law simulation and the MoLE activities as flexible enough to be used in any of several different classroom setting, including in lecture, in demonstration mode, under the control of the teacher, as a homework assignment where students work individually to answer specific questions and/or collect data, as a laboratory assignment in a computer laboratory, and as a cooperative-learning activity used in small groups.

We invite anyone interested to obtain the latest version of the inquiry-laboratory guide, and to access the simulation to use in his or her classrooms. We encourage feedback and suggestions on how to make the materials more useful.