Interactive Digital Overheads: Dynamic Teaching Tools for the Chemistry Classroom

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Abstract: We showcase and describe a collection of digital Web-based teaching tools, highly adaptable to diverse teaching needs and styles and designed to foster conceptual understanding of chemistry via interactive visualization. These resources target many of the topics traditionally addressed in the general chemistry curriculum and are widely available to chemistry instructors and students on the Web. We also analyze and discuss the impact that the use of these tools has had on our teaching practices.

Introduction

Chemists have developed a variety of representations, such as molecular models, chemical formulas, and equations, to describe and explain natural phenomena. This chemical language allows us not only to convey information in a succinct and efficient way, but also to think visually about chemical structures, interactions, and processes [1]. Chemical representations are thinking tools with extraordinary explanatory and predictive powers, which serve as a vehicle to link microscopic models of matter to the actual properties and behavior of macroscopic systems. Their proper manipulation, however, demands a level of understanding that few students are able to reach in our introductory chemistry courses [2].

Conceptual understanding of chemistry requires that students learn how to represent chemical problems using macroscopic, microscopic (particulate), and symbolic forms of representation [3]. For example, they may be expected to recognize diamond and sodium chloride from real images of these substances, draw how their atoms and ions are arranged in the corresponding lattice structures, and identify the chemical symbolism used to label these systems (C, NaCl). Learners should also be able to use these visual models and symbols to describe, explain, and predict chemical properties and phenomena in terms of the interactions between atoms, ions, and molecules [4]. They should understand not only the meaning, but also the scope and limitations of each of these representations. Learning in this context involves students’ abilities to mentally manipulate two- and three-dimensional objects, identify visual patterns, recognize graphic conventions, and decode and translate visual information [5].

Educational research has shown that the use of animations, simulations, and other visualization tools fosters the understanding of fundamental concepts and ideas in the chemistry classroom. In particular, computer-based technologies have proven to be particularly useful in helping students develop scientific models about the composition of matter and overcome common misconceptions [5–12]. Among other things, computer technology has the capability to [13]

- provide multiple and simultaneous representations of the same phenomena at the macroscopic, microscopic, and symbolic levels;
- support molecular-level animations and simulations of chemical phenomena that are not perceivable by other means;
- generate dynamic and interactive simulations that allow the user to explore the effect of changing relevant variables in a system;
- provide immediate feedback about the behavior of a chemical system or process.

Our current chemistry students have been born into a culture mediated by television and the computer. Many of their out-of-school activities involve interacting with rich and sophisticated dynamic images in TV programs, movies, videogames, and other applications of computer technology. They have thus acquired a highly developed visual–spatial intelligence and talent that current teaching practices fail to exploit [14]. The introduction of visualization tools in the chemistry classroom that promote critical thinking and communication via dynamic and interactive images may then help students develop a more solid understanding of central chemistry concepts and ideas.

In the past ten years, the rapid advances in technology combined with the increasing interest in the development of research-based teaching strategies have resulted in the creation of powerful visualization aids and tools for learning chemistry. These include eChem [15], CMM [16], 4M:Chem [4, 17], Connected Chemistry [18], and Chemsense [19]. These highly innovative and interactive tools create opportunities for students to build their own molecular representations and animations, explore the dynamic behavior of chemical systems, and collect and analyze their own data; however, most of these software packages have been designed for individual or small-group instruction at the secondary school level and must be downloaded onto a personal computer. These features have limited their use in certain settings.

The development of the Internet has opened new avenues for the creation and delivery of interactive visualization tools. A simple Web search for “chemistry visualization” reveals a significant number of Web sites that provide access to a variety of 3-D molecular visualization libraries, Java applets, and dynamic Flash movies. The main limitations of these tools are that the quality of the animations and simulations strongly varies from site to site and that most of them have been created for specific purposes, thus restricting their use in different
Interactive Digital Overheads: Dynamic Teaching Tools

Figures 1 and 2 illustrate the wide scope of our building IDOs. On one end, we have simple drawing tools that can be used to draw electron configurations for single atoms (Figure 2a) or draw and graphically add bond dipole moments to analyze the polarity of simple molecules (Figure 2b). At the other extreme are more sophisticated tools that can be used to build the Lewis structure of small molecules and generate their corresponding 3-D molecular structure (Figure 2c). These resources are designed to foster conceptual understanding of chemistry via interactive visualization. The development of these resources has been guided by results from educational research on visualization in chemistry [5, 13], alternative conceptions [21–23], and how people learn [24].

In order to make it easier to find the right application, tools are classified by topic on the main page of the Web site [20]. These topics include the microscopic world, atomic structure, molecular structure, states of matter, chemical reactions, chemical kinetics, and chemical equilibrium. Simple instructions and basic plug-in requirements for each of the tools are displayed before the user selects any of these resources. The IDOs that have been developed so far can be divided into three main groups based on their capabilities and scope: (a) direct visualization tools, (b) building tools, and (c) simulation tools. Let us explore some of the essential features of the different types of IDOs.

(a) Direct Visualization Tools (Figure 1). These resources offer the lowest level of interactivity in that they are designed to help students visualize, compare, and contrast different types of chemical representations, such as molecular structures, atomic spectra, or atomic orbitals. Some of these tools allow instructors to present different representations of the same information, which may help students recognize common visualization features or translate information from one representation to another. In particular, many of these IDOs allow students to manipulate and interact with 3-D representations of chemical structures and models. These tools are also useful to pose questions and problems that require students to analyze data presented in a visual form in order to derive other useful information (e.g., determine molecular formulas from molecular structure, identify bond angles, and locate nodes in atomic orbitals).

(b) Building Tools. Several of the IDOs allow users to easily create microscopic or symbolic representations of a variety of systems and processes. Many of these tools include images that one can click or click and drag onto the main screen in order to draw molecular structures or build microscopic models of chemical substances and reactions. Within this category, we also include tools that allow users to simplify the representation and analysis of graphical data, build concept maps, or create simple animations of chemical systems.

The development of our IDOs is in part motivated by the recognition that although chemistry instructors may share similar learning goals, many of them have varied ideas about what kinds of questions or problems are best suited to help students comprehend or apply a concept, when it is most appropriate to introduce an idea during a course, and how to most effectively engage students in thinking about chemical phenomena. In that sense, our IDOs are not prescriptive tools embedded in a rigid learning environment linked to a particular textbook, Web page, or software package. Rather, they are a collection of digital Web-based teaching tools, highly adaptable to diverse teaching needs and styles, and designed to foster conceptual understanding of chemistry via interactive visualization.
Figure 2. Examples of building IDOs: (a) Electron configuration builder. (b) The VSEPR tool allows users to interact with basic 3-D structures and draw and add bond dipole moments. (c) Our molecule builder transforms 2-D structural formulas into 3-D representations. (d) The movie builder can be used to create static and dynamic microscopic representations. (The interactive version of this figure is available in the supporting materials.)

designed to help students form 3-D mental images from 2-D structures, and compare the differences and similarities between these types of representations. We have also devised tools that can be used to generate both static and dynamic microscopic representations of chemical substances and processes (Figure 2d). In particular, our “movie builder” allows users to create simple movies based on a series of images that are played in sequence and can be saved on a local computer.

The use of building IDOs in the classroom simplifies the introduction of complex representations of chemical systems and creates opportunities for students to develop more sophisticated representational skills. The tools allow instructors to build clear and concise visualizations of microscopic systems directly in the classroom and provide students with the opportunity to generate their own representations, which they can readily share with their classmates. These resources can also be used by students and instructors to create images of microscopic systems with a quality similar to those found in textbooks—images that can then be used to illustrate their homework, school projects, and presentations.

(c) Simulation Tools. The third type of IDOs are designed to help students recognize and explore the dynamic and interactive nature of scientific models of matter. A considerable amount of research has shown that many chemistry students have a static view of the microscopic world, and thus fail to build explanations based on the movement and interactions of atoms and molecules. Although animations of chemical phenomena may help learners visualize the actual behavior of a system, they tend to illustrate a system’s behavior only under fixed conditions. In that sense, interactive simulations are more powerful learning tools to the extent that they allow users to control the system’s evolution and explore the effect of multiple variables.

We have developed a variety of simulations of chemical systems, most of them based on simple particulate models of matter that can be studied using methods of molecular dynamics [25]. Figure 3a, for example, depicts an IDO that can be used to explore the properties of different states of matter (liquid, solid, gas) and their corresponding phase transitions. These types of simulations not only allow instructors to show the dynamic evolution of the system, but also ask students to explore or predict basic relationships between relevant variables. Data can be stored and represented in graphic form in real time on the same screen; this feature can be used to analyze the system’s behavior and to help students establish links between different types of representations (dynamic images and real-time graphs).

Molecular dynamics has been used to create simulation IDOs that model not only physical processes, but also the formation of molecular and ionic compounds, the kinetics of simple reactions, and chemical equilibrium. We have also started to develop simulations based on simple mathematical models that are useful to illustrate or explore the evolution of chemical systems, even though they do not rely on a specific particulate model of matter. That is the case of our stoichiometry IDO through which users can choose a variety of chemical reactions, select the amounts of the reactants, and predict and verify the outcome in terms of the amount of substances produced and remaining (Figure 3b).
Interactive Digital Overheads: Dynamic Teaching Tools

Effects on Teaching

We have used our general chemistry courses for science and engineering majors at the University of Arizona to test and refine each of the IDOs over the past three years. These courses cover the topics listed in a traditional introductory chemistry textbook and are taught in a large lecture hall with a capacity for 300 students. The classroom is equipped with the necessary audiovisual equipment in order to project onto two large screens any information displayed on a computer monitor. The room has also a high-speed Internet connection. This year, a computer was installed for the first time in the room. The IDOs are used on many occasions as the classroom, we are firmly convinced that most instructors and students will benefit from the dynamic and interactive nature of these resources.

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Supporting Material. The interactive versions of all figures are available in a Zip file (http://dx.doi.org/10.1333/s00897050865a) or are available on the Internet or by contacting the authors (see reference 20).

References and Notes

20. All IDOs are widely available to chemistry instructors and students at http://www.chem.arizona.edu/chemt/ido.html (accessed Jan 2005) and may be used for any instructional purposes (classroom activities, development of movies, images, transparencies, overheads, etc.) Instructors with limited access to the Internet may contact the authors (V. Talanquer at victente@u.arizona.edu and J. Pollard at jpollard@email.arizona.edu) to ask for copies of individual Flash movies and Java applets that can be easily installed on their personal computers to be used off-line. The Chime plugin is available at www.mdl.com and the Java plugin is available at http://www.java.com/.