A Study of Web-Based Learning Environments focusing on Atomic Structure

Abstract

The World Wide Web is a promising medium for chemical education. The availability of huge chemical databases, of three-dimensional and dynamic graphics together with the computational power and the communicational features of the Web, offer exciting new ways to learn complicated chemical phenomena. However, to what extent do Web authors in chemistry utilize these advanced tools? We developed a classification scheme, and examined 95 Websites that teach atomic structure. The results show that advanced communication means and graphical tools are rarely used. While the content of the majority of Websites can be considered reliable, their structure, level of graphics, and content resemble an online version of textbooks rather than constituting a new, interactive, learning environment. Nevertheless, we claim that the transition into Web-based learning is only at its inception. We identify the potential of using the Web for chemical education and provide specific examples.

Overview

Over the last few years, the Internet has become a promising new medium that allows people to communicate, work, trade, spend leisure time, as well as to learn. Four main characteristics of the Internet make it especially attractive for science education. These are its data storage abilities, its advanced graphics features, novel communication tools and its ever growing computational power. Application of these tools has changed the way we deal with chemical information by creating opportunities to view molecular structures, simulate chemical processes and communicate with experts from the academy and industry. Such possibilities were not available before, and when utilized wisely, can give rise to exciting learning adventures (Kozma, 2000; Nakhleh, Donovan & Parrill, 2000).

Teachers, lecturers, and educators at all levels, world wide, are showing growing interest in Web-Based Learning (WBL). Lectures notes, homework assignments, online books, and complete courses in science topics such as chemistry, physics, and biology, together with interdisciplinary topics such as environmental engineering and others, can now be found on the Web (Berenfeld, 1996;, Berge & Collins, 1998; Owston, 1997). Many Websites provide instructions for the translation of courses to the Web (Judd, 1998). Moreover, many academic institutions have established special units that lead and support the translation of courses to the Web, aiming at student outreach (e.g., UCF Virtual Campus; Stanford Center for Professional Development).

Historically, each time a new technology emerged, this stirred up expectations for better educational results. Such a trend was evident with the arrival of the radio, the television and the personal computer. Thus, many researchers, educators and politicians now speculate whether the Internet will create a revolution in education. A quantitative research of educational Websites needs to be performed. This paper surveys and evaluates the current usage of the World Wide Web for chemical education. In this context, several questions arise: to what extent do Web authors in chemistry exploit the tools offered by the Web? What new pedagogical models do they apply? What characterizes the resulting curriculum, and how does it differ from the traditional curriculum?

In order to answer these questions, a mapping procedure of educational Websites is needed. Recently, Nachmias, Mioduser, Oren and Lahav (1999) constructed a comprehensive classification scheme of educational Websites. Their classification scheme, or taxonomy, introduced about 100 variables in four dimensions: the descriptive dimension (e.g., target population, site developers, language), pedagogical dimension (e.g., instructional model, instructional means, cognitive demands), knowledge dimension (e.g., representational structure and means, navigation tools) and the communication dimension (e.g., links configuration, distant learning modes).

Mioduser *et al.* (Mioduser, Nachmias, Oren & Lahav, 1999; Mioduser, Nachmias, Lahav & Oren, 2000) applied the above taxonomy to 436 educational Websites. They found that the main component shared by most sites was the information-base, built upon the hypermedia-CD model. As for interactivity features based on the implementation of new technological resources (e.g., Java applets, Shockwave), most online activities resembled the automatic-feedback (behaviorist-like) transactions of classic Computer Aided Instruction (CAI), such as multiple-choice questions. Mioduser *et al.* explained these results by claiming that assimilation of a new technology requires a transition period. This period is characterized by a replication of known pedagogical models by means of the new technology.

The taxonomy proposed by Nachmias *et al.* (1999) did not deal with central issues related to the scientific content of educational Websites. We have therefore constructed a modified classification scheme for Websites that focus on science education (Nachmias & Tuvi, 2001). The modified taxonomy had an additional dimension: scientific content. This dimension included parameters such as graphical representation of science, scientific reliability, level of mathematics, the number of experiments described, interaction between science, technology and society and historical aspects of science.

We then applied the modified taxonomy to examine the pedagogical and technological state of 95 Websites that teach atomic structure (Tuvi & Nachmias, 2001). It was surprising to find so many Websites dedicated to such a specific topic. Most of the sites were found to be scientifically reliable, and they used the inherent structure of the Web (i.e., hypertext that can be accessed in different ways). Images were used frequently for the purpose of illustration. However, in accordance with the findings of Mioduser *et al.* (1999), more advanced technology was difficult to find, and implementation of new pedagogical ideas (e.g., constructivism) was very limited.

Nevertheless, several fascinating Websites of high pedagogical quality that focus on atomic structure do exist. In what follows, we explore the way Web-based learning can contribute to chemical education and provide specific examples. The next section describes the main findings concerning atomic structure Websites. We then discuss the unique potential of the Web for chemical education and provide specific examples. For convenience, the URLs of the quoted Websites are listed at the end of the paper. Since Websites get regularly updated, and as new ones are created each day, the list of Websites discussed here is by no means complete or representative.

Atomic Structure on the Web - Quantitative Analysis

For the purpose of evaluation of the current state of WBL in the field of atomic structure, 95 Websites that focus on teaching the topic were selected, mainly by using search engines on the Internet (e.g., http://www.yahoo.com; http://www.google.com) in addition to random browsing. The criteria for selecting a site were:

1. The site was deliberately developed for educational purposes.
2. The site's contents focus on atomic structure.

All sites were evaluated according to the taxonomy discussed above (Nachmias & Tuvi, 2001). The evaluation process was carried out from November 1999 until April 2000. In May 2000, each site was visited again, and its evaluation was revised. A list of all Websites can be found at http://muse.tau.ac.il/wbl/wbl_atom.html.

Site Authors, Audience, Discipline and Language

About two thirds of the sites were written by academic authors, for undergraduate students. Schools, museums and other organizations were the authors of the remainder of the sites. The primary discipline of two thirds of the sites was chemistry. Physics was the discipline of about 24% of the sites. Except for one site which was written in French, all sites were written in English.

Pedagogical Models

The pedagogical variables that represent the sites in our study are described in Table 1. As is evident from Table 1, the dominant pedagogical model of these

Websites is an information base which claims work with the student's memory. This type of model is designed to be browsed by the individual student. The sites are self-contained with regards to learning resources, with only about 40% of them referring users to external resources (whether online or printed). On average, one out of five Websites provides some sort of feedback, help or test. In other words, from a pedagogical point of view, the vast majority of Websites resembles an online textbook.

Representation

The organization of the text within a site takes the shape of various representational structures: one page, linear (one page after the other, no skipping), branching structure (a tree like structure) or hypertext. Out of the 95 sites in our study, two thirds of the sites used the inherent structure of the Web thus creating a hypertext that allows random navigation within the site. Eighteen percent of the sites included only one html page. The usage of static images was frequent - 60% of the sites included more than one image per page. However, dynamic images, interactive graphics, sound and video were rarely found.

Table 1. Parameters of the pedagogical dimension (N = 95)

Category	Details	%
Instructional configuration	Individualized instruction	100.0
	Classroom/Web collaborative learning	0.0
Instructional means	Information base	97.9
	Tools	5.3
	Structured activity	3.2
Interaction type	Browsing	100.0
	Information gathering	20.0
	Simple activity	8.4
Cognitive process	Memorizing	98.9
	Information retrieval	21.1
	Data analysis/Problem solving	8.4
Feedback	Automatic or human feedback	16.8
Help functions	Technical or content based help	17.9
Learning resources	Within Website resources	97.9
	Linked WWW resources	41.1
	External resources	40.0
	Ask a peer	3.2
Evaluation	Standardized test items	20.0

Communication

In this category we looked at the number of external links a site offers, and the communication means it involves (e.g., e-mail, discussion group). More than half of the sites did not include even one external link. The e-mail address of the site's author was provided by 72% of the sites investigated. Other communication means were found in negligible percentages.

Scientific Content

Table 2 summarizes the results with regards to the scientific content of the Websites. On one hand, the results are encouraging: 83% of the sites present reliable scientific contents. The reliability was tested with regards to the parts of the text that discussed atomic structure, while disregarding the rest of the content. A site was claimed "questionable" if there were misleading statements, wrong equations, or problematic interpretation of scientific data, as compared with the information presented in general chemistry textbooks (e.g., Whitten, Davis & Peck, 1996). Minor inaccuracies with regards to dates of scientific findings and discoveries were not considered to be mistakes in our study, nor did simplified, though inaccurate, models of the atom that are common in elementary explanations of atomic structure. The distribution of mathematical levels indicates that a variety of approaches to teach the topic are employed by Web authors. Illustrations also appear in relatively high percentages (72%) and they enrich the content with images of experimental setups, theoretical models, and more.

On the other hand, experimental procedures are discussed much less than theoretical models. Advanced graphics is barely used. Issues concerned with the interaction of science technology and society appear in negligible percentages, and current research regarding the topic is rarely mentioned.

The distribution of sites according to distinguished experiments and theoretical models, presented in Table 3, stresses these points even further. The structure of the atom, as presented by most Websites, is the simplified Bohr model. While this could be considered adequate in high school chemistry courses, college level Websites should discuss the structure of the atom in quantum mechanical terms, in accordance with general chemistry textbooks (e.g., Whitten, *et al.* 1996). As two thirds of the sites were written by academic authors for undergraduate chemistry students, this finding is surprising.

Table 2. Parameters of the scientific content dimension (N = 95)

Category	Details	%
Reliability	Reliable	83.2
Mathematical level	Elementary	23.2
	High	49.5
	Academic	27.4
Interaction of Science, Technology and Society	Ethical, environmental or usefulness issues	9.5
Number of experiments mentioned	None	40.0
	1-2	29.5
	≥ 3	30.5
Number of theoretical models mentioned	None	12.6
	1-2	36.8
	≥ 3	50.5
Graphical representation	Simulations	18.9
	Photos	17.9
	Figures of data	16.8
	Illustrations	71.6
Historical and current trends	Timeline included	11.6
Latest research results	None	54.7
	≤ 1940	36.8
	1941 - present	8.4

Table 3. Distribution of sites by important experiments and theoretical models (N = 95)

Experiment	%	Theoretical model	%
Rutherford’s gold foil experiment	21.1	Bohr’s model of the atom	55.8
Thomson’s discovery of the electron	20.0	Rutherford’s model of the atom	37.9
Spectroscopy of the hydrogen atom	16.8	Atomic orbitals	33.7
Discharge tubes, cathode/canal rays	15.8	Dalton’s atomic theory	28.4
The photoelectric effect	14.7	Planck’s theory on the quantization of light	26.3
Milikan’s oil drop experiment	11.6	De-Broglie’s theory on the wave-particle duality of matter	26.3
Black body radiation	10.5	Heisenberg’s uncertainty principle	21.1
Identification of the neutron	10.5	Thomson’s "plum pudding" model	18.9
Röntgen discovery of X-ray	6.3	Einstein’s theory on photon-electron collisions	18.9
Discovery of radioactive isotopes: U, Ra, Po	6.3	Rydberg’s empirical equation	16.8
Identification of the proton	5.3	The Schrödinger equation	16.8
Early experiments related to existence of atoms	3.2	Democritus’ philosophy	13.7

Exploring the Potential of the Web

The analysis of the Websites in our study may give the impression that the pedagogical contribution of the Internet to chemical education is shallow. Mioduser *et* *al.* (1999) summarized the situation as follows*: "One step ahead for the technology, two steps back for the pedagogy"*. As experienced educators we hold substantial models regarding the various facets of our practice (e.g., how to build a lesson plan, to assess a learner's performance or behavior, to develop a learning unit). These models are usually tied to the technological resources at hand, and they affect each other mutually. When facing the assimilation of a new technology we use these models as input to the process. As a result there is usually a transition period at which we replicate the known models by means of the new technology. But, this transition period is a necessary step that allows us to explore the potentials of the new technology. In what follows, we describe and exemplify several trends in use of the Internet that are likely to create a difference in chemical education.

New Pedagogical Models

The Web offers many tools that allow the implementation of current pedagogical models. These models support the students' active involvement in the construction of knowledge, their interaction with peers and experts, the adaptation of instruction to individual needs and relevant ways to assess the student's learning. Active learning is one of the main goals of the constructivist approach. According to this model, the student is responsible for the learning process: it is he or she who asks the questions, finds the information and provides the answers. The teacher on the other hand, takes the role of a mentor rather than a knowledge provider.

The availability of chemical databases on the Web creates endless opportunities to activate such learning processes by data manipulations. One example is Webelements (http://www.webelements.com) - a comprehensive database of the periodic table that includes text, pictures and movies on the physical and chemical properties of each element. Another example is *ChemFinder* (http://www.chemfinder.com) - a database of molecules that can be searched by molecular formula, molecular weight or molecular structure. The site provides physical properties of the molecules and many links to additional information about specific molecules on the Web.

Another aspect of active learning is the availability of an experimental environment. In the laboratory, students can perform experiments individually or in groups, thus explore many important scientific concepts. On the Internet, such an environment can be created by the use of interactive simulations and take-home experiments. The Miami Museum of Science at http://www.miamisci.org/af/sln is a good example of such an environment. This site, aimed at high-school students, creates an active learning environment in which the learning takes place both online, and at home via take-home experiments for the individual, and suggestions for group activities in class. The site also uses interactive simulations to exemplify certain ideas, and provides an attractive, easy to understand learning atmosphere.

A different approach is Web-based collaborative learning. Here the novel communication features of the Web are used to create an environment that enhances students' interaction with experts and with peers. The chemistry section of the Scientific American: Ask the Experts (http://www.sciam.com/askexpert)6 site is one example of the usage of these tools. Science experts can help teachers cover special topics, in which the learning resources are not suitable for the level of the students, or are rare to find. Such topics could be current research advances (e.g., combinatorial chemistry), multidisciplinary subjects (e.g., environmental chemistry) or industrial procedures and patents.

The *Think Quest*[7] project, http://www.thinkquest.org, is another example of collaborative learning. Here teachers and students from various schools and colleges around the world are competing collaboratively to create educational Websites on miscellaneous scientific topics. The results of this contest are numerous Websites in, for instance, chemistry, physics or biology, which provide reliable educational resources.

Novel Communication Tools

The traditional learning process takes place in the classroom, where students and teachers can interact and discuss the topics being studied. However, at home, the learning process becomes individual. Students need to cope with their homework on their own, with no help from their teachers. While the ability to study on one's own is an important goal of any educational process, many students fail to complete their work without proper help, especially in scientific subjects such as mathematics, physics and chemistry. The Internet provides several tools to cope with such difficulties by facilitating communication opportunities. The use of asynchronous discussion groups and synchronous chats, with or without mentor, allows the learning process to continue beyond the classroom boundaries of time and place (Paulisse & Polik, 1999). A good example for these features is the *Atomic Alchemy* Website (http://library.thinkquest.org/17940) from the *Think Quest* library. This site has a complete interaction section that includes a discussion forum, question forum, surveys, online test and a guest book.

Hypertext Authoring

Another unique attribute of the Internet is the ability to connect one site to the other. The number of links in a site, and the extent to which a site's content relies on other existing sites can be considered important parameters in determining its quality. The hypertext nature of Websites allows one to put together a good Website without writing "new" content, but rather by classifying existing Websites in the field of interest. One excellent example of this feature is the *Science Help Online* - a site of Fordham Preparatory School in New York City (http://www.fordhamprep.pvt.k12.ny.us/gcurran/tutor2/rcindex2.htm). Here general chemistry is explored in the form of simple explanations followed by specific links and take-home exercises. Each explanation is given with one or more links that are briefly explained. Thus, students are referred to additional information in a didactical fashion, which can contribute to the increase of students' curiosity.

Knowledge Representational Features

Research has shown, that presenting the same content using different modalities (e.g., verbal - as text, visual - as images) can enhance the learning process (Plass, Chun & Mayer, 1988; Mayer, 1997). The variety of the representational tools that the Internet has to offer makes it an effective medium for science learning. Beyond two-dimensional, color images, which can also be found in textbooks, the Internet offers three-dimensional, interactive images, dynamic and/or interactive simulations, sound effects and video material. The advantages of computer simulations are governed by the recent meta-analysis of Bayraktar (2002). She compared the effectiveness of Computer-Assisted Instruction (CAI) and traditional instruction on student achievements in secondary and college science classes and showed that computer simulations are the most effective mode of CAI. In a more specific research, Wu, Krajcik and Soloway (2001) showed that students can develop better understanding of chemical representation when using a computer-based visualizing tool called "eChem" that allowed construction of molecular models and a simultaneous view of multiple representations. The following Websites exemplify the usage of the various representation tools in chemistry and physics.

1. The *Physics 2000* site, http://www.colorado.edu/physics/2000/cover.html, from the University of Colorado at Boulder is enriched with many dynamic and interactive simulations. These simulations present many aspects of atomic structure, including wave characteristics of light; properties of the light spectrum; the electric force inside the atom; atoms behavior in a magnetic field and laser traps. Other topics such as the periodic table, radioactivity and electromagnetic radiation in daily life (e.g., microwave ovens, TV screens) are discussed as well.
2. A valuable usage of sound is made by the site *A Look Inside an Atom*- from the Center for History of Physics at the American Institute of Physics (http://www.aip.org/history/electron/jjhome.htm). This site presents an exhibition about J. J. Thomson and the discovery of the electron. It includes an original audio recording of J. J. Thomson, discussing his own findings. In addition, this site contains photographs of old experimental apparatus used by Thomson and his colleagues in the 19th century.
3. The *VRML File Creator for Chemical Structure*, http://www2.chemie.uni-erlangen.de/services/orbvis/index.html, is an interactive tool for drawing three-dimensional chemical structures. The user is provided with a simple chemical editor in which a two-dimensional molecular structure can be drawn.

> Upon submitting this structure, a three-dimensional picture in VRML format is obtained. The VRML format allows user manipulation of the structure such as rotation, translation, change of color scheme, perspective angle and more.

Scientific Content

Scientific content can be presented in many ways. Here we point out several sub-categories that can create a difference when using the Internet as an educational medium.

Comprehensiveness

The Internet has unlimited space. Because of the hypertext nature of the content, sites have unrestricted size. As a result, finding well-organized, comprehensive sites that deal with specific content is not easy. We would like to point out the *Particle Adventure* site, http://ParticleAdventure.org, which teaches particle physics in the space of over 100 html pages in a very comprehensive, self-contained fashion.

Authentic Learning

Chemistry is an ever-developing field. Scientists discover new phenomena and theoretical models all the time. These new findings, once reviewed and approved, are published in scientific journals, addressed mainly to experts in the field. To many teachers, and certainly to students, these journals are unreadable. Their main sources of information are textbooks. However, textbooks take much longer to publish. Consequently, textbooks are updated with information that is at least 2-3 years old by the time they reach the bookstores. The Internet on the other hand, allows immediate updating. Good educational Websites, not only use the Web tools for better graphical representation or creation of interactive environments. They also present accurate up-to-date information, which is consistent with the latest research in the field. This feature can give rise to more authentic learning processes.

The *Particle Adventure* site, http://ParticleAdventure.org, is a good example of this feature. On its homepage, there is a narrow frame on the left, which is constantly updated with recent scientific findings in the field of particle physics described in simple terms. Another example of this feature is the *Webelements* site (http://www.webelements.com). While printed periodic tables contain 109 elements (see for example Whitten *et al.*, 1996), the *Webelements* site presents 115 elements, including elements artificially prepared by leading researchers in the field.

History of Science

The structure of the atom was not discovered in one day. It involved a long process in which many talented theoretical and experimental researchers took part. Understanding the details of this process can shed light on the nature of scientific thinking, the collaboration between scientists which is essential for progress, and the role played by the media, politics and cultural differences.

Several sites on the Internet devote attention to historical aspects of atomic structure research and present detailed timelines. The A*tomic Alchemy* site, http://library.thinkquest.org/17940, presents a detailed timeline with scientific achievements as well as related ethical and political treads worldwide. The *Particle Adventure* site and the *Physics 2000* site (http://ParticleAdventure.org ; http://www.colorado.edu/physics/2000/cover.html) both contain a detailed scientific timeline including very recent findings. *Carmen Giunta's Classic Chemistry Page*, http://webserver.lemoyne.edu/faculty/giunta, is an excellent Website that explores chemical history. This site contains over a hundred historical papers by distinguished scientists such as Dalton, Thomson, Bohr, Rutherford and many more. Beyond its historical and scientific importance, the accessibility of such material on the Web, free of charge, can augment the service provided by institutional libraries.

Experiments and Models

In order to fully understand a scientific topic, one should be able to understand experimental procedures and the theoretical models related to the topic. Students should be given the tools that will enable them to judge whether a certain conclusion does or does not result from an experimental measurement, and whether a theoretical model does or does not explain the experimental results. On scientific Websites it is common for science to be represented as a collection of facts only. However, in our study, we came across several Websites that offer a comprehensive discussion of the experimental and theoretical research on atomic structure with many illustrations. Two of these sites are *General Chemistry Web Course Tutorial,* http://wine1.sb.fsu.edu/chm1045/chm1045.htm, which contains many illustrations of old experimental apparatus in addition to theoretical models, and *21st Century Science,* http://zebu.uoregon.edu/~js/21st_century_science, which contains high-quality demonstrations in the form of illustrations, dynamic simulations and interactive simulations. The text includes detailed explanations of many experiments and models, and adds various historical details.

Interaction of Science, Technology and Society

The world today is one big global village. New scientific findings have almost immediate effects on our lives, regardless of where we are. For example, the success of the cloning procedure of the sheep Dolly, led to enhanced discussions on the ethics of cloning worldwide. Advanced research on chemical weapons in Iraq has changed the national defense policy of several countries in the Persian Gulf, the Middle East and the United Nations. Such strong and immediate influence is a result of advanced communication means, of which the Internet is only one part. This can become an advantage, if used to teach scientific content in the context of current political, sociological and economical circumstances. As a result, students can become more aware of their surrounding. The diversity of resources on the Internet, and its hypertext nature, support such perspectives. The *Atomic Alchemy* Website, http://library.thinkquest.org/17940, is one example for this approach. In the timeline presented on the site, along with research done on particle physics, much attention has been given to worldwide rules and regulations concerning nuclear radiation.

Summary

The Internet has a lot to offer to science education. New pedagogical models, such as collaborative learning, can be practiced by utilizing the communicational tools of the Web. The hypertext nature of the Web allows each author to contribute his/her own specialty to the overall comprehensive information network. Interactive simulations provide ways to demonstrate scientific principles that can not be demonstrated due to cost and time restriction, or for reasons of safety. As educators, many of us have learned to rely on textbooks as the main source for information and didactics. The new medium of the Internet has several advantages that can, at least partially, supersede textbooks. If we take the time to explore this new medium, we shall be able to substantially affect learning processes.

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