EDUCATIONAL WEBSITES IN CHEMISTRY - EXPECTATIONS VERSUS REALITY

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ABSTRACT
The World Wide Web is a promising medium for chemical education. The huge chemical databases, the three-dimensional and dynamic graphics together with the computational and communicational power, offer exciting new ways to learn complicated chemical phenomena. However, to what extent do Web authors in chemistry utilize these powerful tools? Our research attempts to answer this question. We have 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 a new, interactive, learning environment. These findings are discussed along with concrete examples.

KEYWORDS
Internet, taxonomy, science education, web-based learning, atomic structure.

INTRODUCTION

Over the last decade, 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 in general and chemical education in particular. These are its data storage abilities, its advanced graphics features, its 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., Distributed Learning at the University of Central Florida, Stanford Online).

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 if we want to substantiate these claims. In this work we survey and evaluate the current usage of the World Wide Web for chemical education. In this context, several questions arise: to what extent do Web authors in chemical education 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? This paper is aimed at answering these questions.

Our attempt to answer the above questions quantitatively as well as qualitatively was based on two main steps. The first step involved a definition of a classification scheme of educational Websites by which they can be compared and evaluated. The second step required a careful selection of Websites using well-defined criteria. Given the magnitude of information available on the Web today, we chose to focus our research on a specific topic, rather than categorize enormous number of Website in chemistry. The chosen topic was the structure of the atom, because of its importance in both high-school chemistry curriculum and undergraduate courses in physics and chemistry.

TAXONOMY OF WEBSITES IN SCIENCE EDUCATION

While many educators believe in the unprecedented opportunities and potential offered by the Internet to enhance education, others are intimidated by its somewhat chaotic and unstructured nature. The unlimited freedom, the overwhelming amount of information and the possibility for anyone to take part in the creation of knowledge, are, for many, a barrier to fulfilling the perceived potential. Furthermore, many Websites, although meant to be educational, do not take full advantage of the educational features of the Internet. It is thus necessary to carefully examine the Internet as an educational medium and, similar to research done on science textbooks (e.g., Chiappetta, Sethna, & Fillman, 1991), define a list of criteria by which scientifically oriented educational Websites can be uniformly characterized and evaluated.

Recently, Nachmias Mioduser, Oren and Lahav (1999) suggested a comprehensive taxonomy for educational Websites classification based on the division of the criteria into four dimensions: descriptive, pedagogical, knowledge and communication. This attempt provides a general tool to classify and evaluate educational sites, which are not necessarily scientific in nature. Based on this work, we suggested a revised classification scheme that put emphasis on scientifically oriented educational Websites (Nachmias and Tuvi, 2001). The addition to the four-dimensional taxonomy focused on the scientific content level as expressed via representation of experiments and models, incorporation of mathematical descriptions of natural phenomena, and material based on interaction of science, technology and society. These categories were gathered into a fifth dimension entitled scientific content. In addition, we have adjusted the taxonomy as a whole to the special characteristics of scientifically oriented educational Websites.

The modified taxonomy consists of about 90 variables in five dimensions:

1. *The Descriptive Dimension* (e.g., target population, site developers, language)
2. *The Pedagogical Dimension* (e.g., instructional model, instructional means, cognitive demands)
3. *The Representational Dimension* (e.g., representational structure and means)
4. *The Communication Dimension* (e.g., links configuration, navigation tools)
5. *The Scientific Content Dimension* (e.g., scientific reliability, level of mathematics, number of experiments described, historical aspects of science)

In addition to the classification scheme described above, we have constructed auxiliary tables that list the important experiments and theoretical models related to research on atomic structure. The experiments and models listed were chosen according to several general chemistry textbooks (Whitten Davis & Peck, 1996; Mcquarrie & Rock, 1991; Petrucci & Harwood, 1997) in addition to books about the history of science (Nye, 1996; Idhe, 1984; Cobb & Goldwhite, 1995; Encyclopedia Britannica, 1970) and Atkins' physical chemistry textbook (Atkins, 1998). These tables are designed to give better insight into the experimental and theoretical nature of science as presented by educational Websites in the field of atomic structure.

SELECTION OF WEBSITES

We selected, (mainly by using search engines on the Internet e.g., *Yahoo* (*http://www.yahoo.com*), *Google* (*http://www.google.com*) in addition to random browsing) 95 Websites that focus on teaching the topic. The criteria for selecting a site were:

1. The site was deliberately developed for educational purposes.
2. The site included any sort of explanation (or definition) of the atom concept. Alternatively, the site included instructions for a demonstration aimed at explaining atomic structure.

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.*

SUMMARY OF THE MAIN FINDINGS

We applied the modified taxonomy to examine the pedagogical and technological state of 95 educational Websites in the field of atomic structure (Tuvi and 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 (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 such as (Whitten *et al.*, 1996). Most of the sites 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.* (Mioduser, Nachmias, Oren and Lahav, 1999; Mioduser, Nachmias, Lahav and Oren, 2000), who surveyed 436 Websites in science education using the taxonomy of Nachmias *et al.* (1999), more advanced technology was difficult to find, and implementation of new pedagogical ideas (e.g., constructivism) was very limited.

In what follows, we describe the main findings of our research. For more details, see Tuvi and Nachmias (2001).

Site Identities

Under this title, basic information regarding the location, creators, target population and relevant technical data of a site is included. The information is organized in five categories: *Site identification* (e.g., name, URL, authors' affiliation - academic, public organization, commercial, school or other); *site evolution* (e.g., creation date or last updating, development status); *language* or languages used in the site; *target population* and *size*, the last indicated by the number of html pages.

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. The size of 39% of the sites was less than 10 pages. About half of those sites (18% of the total) comprised only one page, and the other 61% covered more than 10 html pages. A site's size was defined as the size of the whole site, regardless of what part of it was devoted to atomic structure.

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, and designed to be browsed by the individual student. Only 40% of the sites include references 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.

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

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

Representation
Information can be retrieved from any Website, especially educational Websites. It is of great importance, however, to note in what format information and knowledge are presented. The organization of the text within a site can take 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.

Communication
Networking, by definition, implies communication, or people's interaction with knowledge and/or with other people. 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). About 59% of the sites did not include even one external link to other Websites. 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 *et al.*, 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, our results show that 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 important 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. Recalling that two thirds of the sites in our study were written by academic authors for undergraduate chemistry students, this finding is disturbing. According to Shiland (1995, 1997), attempts to describe advanced quantum mechanical models of atomic structure in high school chemistry textbooks failed to provide reasonable justification for the rejection of the Bohr model. While different strategies of teaching atomic structure can be suggested (Tsaparlis, 1997) there is no argue regarding the need to go beyond the Bohr model. Even if we could agree to accept the Bohr model as the highest level of explanation of atomic structure for high school chemistry students, this is not the picture we would like to transfer to college level students. Therefore, one could expect a college level Website to discuss the structure of the atom in quantum mechanical terms, in accordance with college level, general chemistry textbooks (e.g., Whitten *et al.*, 1996). Nevertheless, several fascinating Websites of high pedagogical-quality that focus on atomic structure do exist. In the next section, we explore the way Web-based learning can contribute to chemical education and provide specific examples.

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.

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 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

Ideally, an educational Website should be comprehensive, regularly updated with current research findings in the field, effectively use communication tools and three-dimensional, interactive graphics and rely on various knowledge sources on the Web. In practice however, we can not expect to find everything in one site. In what follows, we list several Websites that use the Internet tools effectively for the purpose of chemical education. Since Websites are being updated regularly, and new ones created each day, the list of Websites discussed here is by no means complete or representative. For a more comprehensive discussion, see Tuvi and Nachmias (in press).

1. *The Particle Adventure*, *http://ParticleAdventure.org*, is a constantly evolving educational project sponsored by the particle data group at Lawrence Berkeley National Laboratory (LBNL). This is a very comprehensive Website, with more than 100 html pages in the field of particle physics. The content is presented in a well-organized, self-contained manner. The subject is presented in the proper historical background - a detailed timeline of important scientific discoveries in the field is given on one hand, while up-to-date findings are described on the other hand.
2. *Physics 2000, http://www.colorado.edu/physics/2000/cover.html* - a site 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.
3. *A Look Inside an Atom, http://www.aip.org/history/electron/jjhome.htm*, authored by the Center for History of Physics at the American Institute of Physics, makes a valuable usage of sound. 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.
4. The *Miami Museum of Science, http://www.miamisci.org/af/sln*, is a good example a virtual laboratory. 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 scientific principles, and provides an attractive, easy to understand learning atmosphere.
5. The *Think Quest*, *http://www.thinkquest.org*, is an example of a collaborative learning project. 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, various scientific topics, which provide reliable educational resources.

6. The *Atomic Alchemy, http://library.thinkquest.org/17940,* which is part of the *Think Quest* library, exemplifies the use of communication tools. This site has a complete interaction section that includes a discussion forum, question forum, surveys, online test and a guest book.
7. *Science Help Online, http://www.fordhamprep.pvt.k12.ny.us/gcurran/tutor2/rcindex2.htm*, is a part of the Fordham Preparatory School in New York City Website. Here a valuable usage of the hypertext nature of the Web is made. 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. In this site, general chemistry is explored in the form of simple explanations followed by specific links and take-home exercises. Each link is described shortly. Thus, students are referred to additional information in a didactical fashion, which can contribute to the increase of their curiosity.

SUMMARY

An enormous amount of information can be found on the Web. Even so, it was surprising to find 95 different educational Websites that focus on atomic structure. We used our specially designed taxonomy of educational Websites to examine these sites. Our main question was whether the advanced learning technologies are supported by any novel pedagogical or curricular paradigms such as constructivism, inquiry based learning or alternative evaluation. Our results, supported by those of Mioduser *et al.* (2000), show that this is not the case. While the information may be considered reliable and the natural structure of the Web is used, true pedagogical and/or curricular change remains an ideal, rather than proven practice. At the content level, science is represented as a collection of facts. The experimental nature of scientific research is mostly ignored. Links to special databases or interactive expert consultation are not applied. Moreover, links to similar sites are rare. Considering the redundant nature of the Web, cooperation between Web-authors could be beneficial. However, our data show that attempts to collaborate over the Web are uncommon. In addition, technology is implemented in its most simple form (i.e., linked text and static images) and advanced technology is rare (e.g., dynamic images, interactive simulations). To summarize, the overall format of these Websites resembles a textbook rather than a new educational environment.

In light of these results, one can adopt the skeptics' perspective and argue that Web technology has little to offer to education. However, as we have shown, several fascinating high pedagogical-quality sites that focus on atomic structure do exist on the Web. Adopting a more thoughtful perspective, one may claim that WBL is currently at a transitional stage. The vast usage of the new technology, even in its simplest form, is a major development in its own right, and a necessary step on the way to a revolution. More research and extensive development of innovative educational models are thus required.

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