Freshmen Learning in A Web-based Chemistry Course[◊]

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Abstract

Chemistry courses in higher education have traditionally been composed of lectures, problem solving sessions and laboratories. This study describes a Web-based chemistry course and the learning outcomes of freshmen that used it. Chemistry faculty and teaching assistants were interviewed regarding their views about Web-based teaching and learning. Students who took part in a Web-based general chemistry course were divided into two groups based on their preference of participating in a Computerized Molecular Modeling (CMM) project. The experimental group students carried out an individualized project using CMM software to represent a complex molecule in three model types, compute its molecular weight, and construct hybridization and electrical charge distribution for each of the carbon atoms in the molecule. Pre- and post-tests along with final examination grades served for assessing the students achievements. The 95 experimental students achieved significantly higher grades than their 120 control group peers in both the post-test and the final examination. The experimental students were able to switch from 1-D to 2- and 3-D molecular representations, argue for selecting an appropriate substance for a particular purpose and transfer between the four levels of understanding in chemistry better than their control counterparts.

Introduction

Simulations, graphing, and microcomputer-based laboratories have been used in the last two decades as effective teaching methods in science education at both college and high school levels (*1-5*). Scientists, engineers and science educators use models to concretize, simplify and clarify abstract concepts, as well as to develop and explain theories, phenomena and rules. Researchers underscored the need for models as enablers of students' mental transformation from two-dimensional to three-dimensional representations (*6-8*). Virtual models enhance teaching and learning of various topics in chemistry. Studies have shown that when teaching topics, such as chemical bonding and organic compounds, is aided by 3D computerized models, students' understanding improves *(9-11)*.

During the past decade, science educators have been engaged in experimental projects that focus on the integration of the Internet and World Wide Web as an additional medium for teaching and learning. The Internet and the WWW are used as a source of scientific data and theoretical information (*12-14*), a tool for designing learning environments (*11, 15-17*), integrating virtual models (*18*), and creating learning communities (*19-25*).

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While teaching the properties of substances and how they react, chemistry educators identified three levels of understanding: macroscopic, microscopic, symbolic (*26-29*). Dori and Hameiri (*30*) suggested additional fourth level – the process level, at which the substance is formed, decomposed, or reacts with other substances. Mastering this process level often requires higher order thinking skills as well as at least two of the previous three chemistry understanding levels. Researchers have shown that plastic and virtual models, such as Computerized Molecular Modeling (CMM), help students develop conceptual understanding (*31, 32)* as well as the ability to transfer across the various levels (*26-28*).

Methodology

Chemistry courses in higher education have traditionally been composed of lectures, problem solving sessions, and laboratories. This study, which took place at the Technion, Israel Institute of Technology, was aimed at developing a freshmen Web-based chemistry course and investigating the performance of the students who use it.

The research objective was to investigate the learning process in a Web-based environment. The research questions were:

(I) How did chemistry faculty, teaching assistants, and students view Web-based teaching and learning?

(II) How did an individual optional computerized molecular modeling project affect the students' learning outcomes?

Research population and setting

The research population consisted of 13 instructors and 53 students, who participated in a survey, and 215 students who participated in three Web-based chemistry courses. The instructors included seven chemistry faculty and six chemistry teaching assistants. Based on students' preference of participating in the optional computerized molecular modeling project, the 215 freshmen were divided into experimental (N = 95) and control (N = 120) groups. Only students who responded to the pre-test, post-test, and final examination were included in the research.

To validate the assumption that the baseline of the two groups (experimental and control) is identical we compared the entry-level grades (SAT and GPA equivalents). These grades are a combination of the high school matriculation examinations and a battery of psychometric tests in mathematics, English and Hebrew of the students in both groups. We found no significant difference between the two research groups regarding their entry-level grades. We also compared the two research groups in terms of their prior knowledge in chemistry and found no significant difference between the two groups.

Students in the two research groups studied in the same class with the same instructor and teaching assistants. Hence, the difference between the two research groups was that the experimental group carried out an individual project, which involved an intensive use of the Web and CMM and credited them with extra 5 points to their course's final grade. The project was handed out at the 6^{th} week, after the students had studied chemical bonding and molecular orbitals and was due for the last week of the semester.

Each student received a different complex molecule, which he or she had to download from the course website. We assigned each student in the experimental group with a certain molecule from a list of substances that are used on a daily basis, including Vitamin A, B, and C, Nicotine, Caffeine, Adrenaline, TNT, and DDT. The project required downloading two shareware programs (*33, 34*), one for writing the structural formula of the molecule, and the other for viewing and manipulating it in three representation forms: framework, ball-and-stick, and space-filling. The student was required to build virtual models of the molecule in three representation modes, compute its molecular weight, construct hybridization and electrical charge distribution for each of the carbon atoms in the molecule, and seek information on the Web about the daily use or applications of the substance.

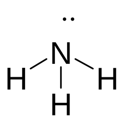
Students carried out the project voluntarily in their free time in addition to the regular course load. The control group students elected not to participate in this activity. All the students in the three courses, regardless of whether or not they elected to undertake the optional individual project, were exposed during lectures to examples of molecules represented by the same CMM software tools (*33, 34*). In addition, two recitation sessions were devoted to practice building molecules with those packages.

Research Tools

Research tools included semi-structured personal interviews with faculty, teaching assistants and experimental students, a students' survey, and pre- and post-tests. The faculty and teaching assistant's interviews, and the students' survey were administered prior to the development of the Web-based chemistry courses. The results served as guidelines for constructing the Internet sites and the CMM project that were used in the courses.

To investigate students' learning outcomes we used chemistry understanding pre- and post-tests, entry-level grades, and final examination scores. The pre- and post-tests were similar and included three questions with images of models that appear in general chemistry textbooks. The tests were aimed at assessing students' chemistry understanding. The first question investigated students' ability to apply transformation between the four levels of chemistry understanding: macroscopic, microscopic, symbolic and process (*11, 30*). The second question, presented in Table 1, investigated students' ability to apply transformation from one-dimensional molecular representation to two- and three-dimensional representations, and vice versa. This question was developed and validated by Dori and Barak (*11*). The third question, which was developed and validated by Reid (*35, 36*) investigated students' ability to answer a higher order thinking skills question.

Table 1. Question 2 of the pre- and post-test

Compound	Molecular formula	Structural formula	Spatial structure	Hybridization (sp, sp^2, sp^3)	Model
Ethanol	C_2H_6O				
				sp^3	
			Triangular pyramid		

Results

Attitudes toward Using Web and IT in Chemistry Courses

Interviews with faculty and teaching assistants indicated that none of them had used information technology (IT) for teaching a general chemistry freshmen course.

Their attitudes towards the use of computers and the Internet in teaching and learning chemistry were mixed and ambivalent. Responses were classified into three categories: (1) Interested in Web-based teaching; (2) Not interested in Web-based teaching; and (3) Undecided. Faculty and the teaching assistants who expressed interest in using the Web, wanted to use it for various purposes, which are listed below along with interviewee responses.

- Information extracting and problem solving: *"I can refer interested students to the Web, so they can find enriching information."*
- Modeling: *"If I had a big screen in the class, I could show the students computerized demonstrations. Even showing one picture or a video clip of an experiment is important."*
- Assessment: *"Students can take a computerized test, and the teacher gets a summary of the results."*

The instructors who were not interested in using information technology indicated that they did not want to change their teaching methods. Some comments were: *"It is fine for a young lecturer who is starting his career," "It is difficult to change old habit,"* and *"I am not familiar with the Internet."* Some were concerned about losing the personal contact with the students: *"I am against the use of computers because I believe we need to work more intimately with the students… to allow students who do not understand the learning material to raise their hands, stop me during the lecture and ask a question."*

The interviewees who were interested in Web-based teaching, expressed reservations regarding the time required for preparing a Web-based course, incorrect information presented on the WWW, technical problems, and the lack of computers in the lecture halls. Conversely, teachers who were not interested in IT-enhanced teaching, mentioned positive aspects, such as the variety of teaching methods, students' motivation, and the ability to visualize abstract concepts.

Analyzing the students' survey, we found that 95% responded positively to the open question, which was "Would you like to learn chemistry in a Web-based and Computerized Molecular Modeling environment? If so, specify the preferred chemistry topics." This indicates that the vast majority of students were interested in learning chemistry in a Web-based environment. More than half of the students chose organic compounds and stereochemistry, and almost one third chose atom structure and chemical bonding. These topics, which are taught in freshmen general chemistry courses, were indeed found in other studies to be best taught with computerized molecular modeling (*9, 11, 31*).

Students who studied in a Web-based environment were asked to specify the number of times and purposes for entering the course Web site. The differences between the experimental group (students who carried out the CMM project) and control group are presented in Figure 1. The site was mainly used for accessing homework assignments, getting their solutions, and reading course summaries. Students who elected to carry out the project were also engaged in reading peer's projects, linking to other chemistry sites and downloading computerized molecular modeling programs.

Only a few students used the forum to contact the teaching assistants and ask them questions. The individual project required an intensive use of the Web and computerized molecular modeling software. Figure 2 shows an example of part of a CMM project.

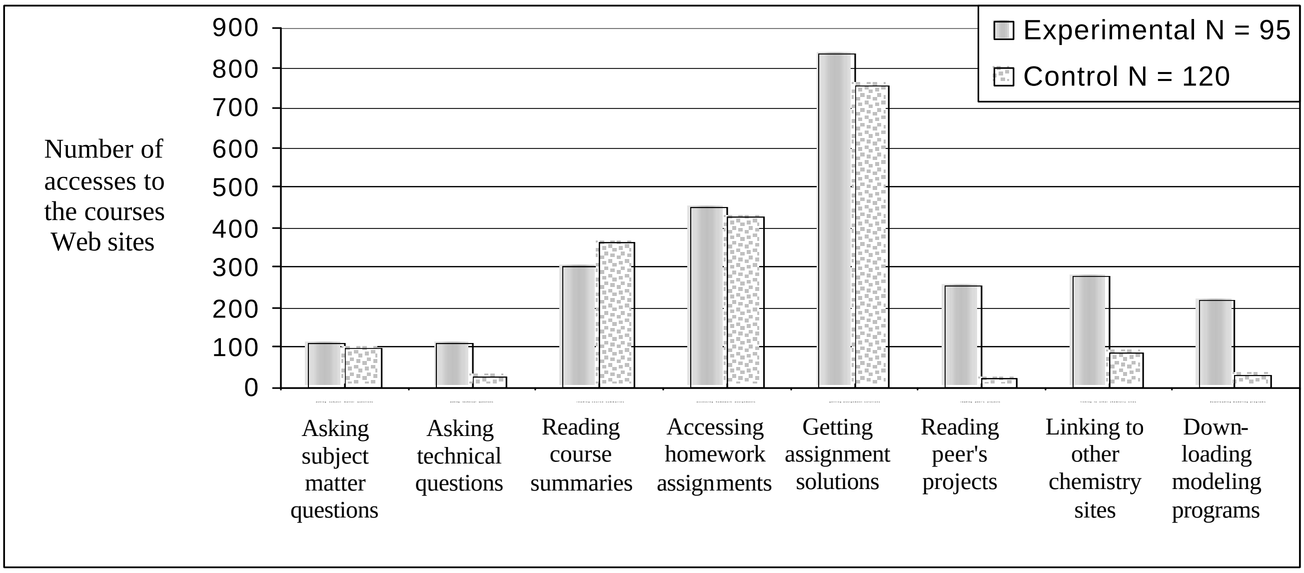
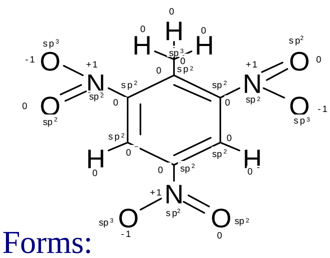


Figure 1. Comparison of frequency and purpose of accessing the courses Web-sites between the research groups

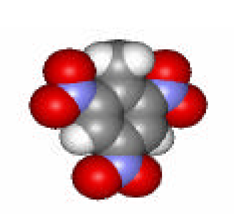
Trinitrotoluene (TNT) molecule

Molecular Formula: $CH_3C_6H_2(NO_2)_3$
Description: pale yellow crystals
Melting point: 82° C (180° F). Its low melting point allows it to be melted and poured into artillery shells and other explosive devices.
Density: 1.65 gr/cm^3
Burns at: 295° C (563° F), but it may explode if confined.
Hybridization and formal charge:

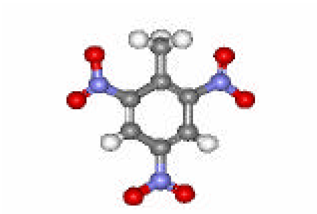


Computerized Molecular Models in Three Representation Forms:

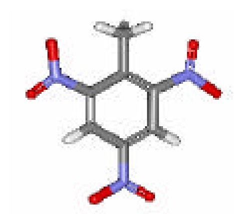
Space-filling



Ball-and-stick



Framework



Trinitrotoluene (TNT) is prepared by the nitration of toluene. Trinitrotoluene is highly explosive, but, unlike nitroglycerin, it is unaffected by ordinary shocks and jarring, and must be set off by a detonator. Because it does not react with metals, it can be used in filling metal shells. It is often mixed with other explosives, e.g., with ammonium nitrate to form amatol.

Figure 2. A student's CMM Project

Students' Achievements in the Web-based Chemistry Course

To analyze the effect of this project on students' achievements, we used analysis of covariance (ANCOVA). Although the pre-test average scores of the experimental and control group students were very close (30.14 and 31.82 respectively) the pre-test scores were used as the covariant for the post-test analysis. The entry-level grade and the pre-test scores were used as the covariant for the final examination analysis. As noted, no significant difference was found between the research groups regarding their entry-level grades and their prior knowledge in chemistry.

Table 2. Analysis of covariance of the post-test and the final examination scores

Dependent variable	Research group	N	$\overline{X}$	SD	F	p <
Post-test score	Experimental	95	72.65	17.56	57.49	0.001
	Control	120	53.52	19.38		
Final exam score	Experimental	95	70.28	18.90	5.19	0.02
	Control	120	62.02	25.23		

Table 2 shows that the experimental group students received significantly higher scores on both the post-test and the on the course final exam. We assumed that the extra activities that experimental students carried out while studying the general chemistry course improved their chemistry understanding and higher order thinking skills to a larger extent than their control group peers.

We analyzed students' responses to each of two questions individually. Question 2, presented in Table 1, tested students' ability to apply transformations to and from one-dimensional molecule representation to two- and three-dimensional representations. To analyze the effect of the CMM project on students' ability to apply transformations, we perform an analysis of covariance (ANCOVA), using the pre-test scores as the covariant (see Table 3). We found that the integration of the CMM project into the general chemistry course was the main source for the difference in the students' ability to apply transformations (scores of question 2).

Table 3. Analysis of covariance of the transformation abilities between three, two and one molecule representation modes in the post-test

Source of variant	SS	DF	MS	F	p <
Learning method (integrating the CMM project)	86.61	1	86.61	26.68	0.001

Analyzing the models students had drawn in Question 2, we found that the experimental group students filled 73% of the blank cells with models (see Table 1), while the control group students filled 51% of the blank cells. Students' drawings of NH_3 (Figure 3) and CH_3CH_2OH molecule models depict typical differences between the two research groups. Space-filling model was the most popular molecule representation among the experimental group, and accounted for 70% of the drawings. Among the control group, the ball-and-stick model was the most popular molecule representation, accounting for 46% of the drawings. As Figure 3 demonstrates, most experimental group students - 83% (as opposed only 5% of the control student) drew the non-bonding electrons in the ammonia molecule model, and some of them drew tetrahedrons models.

Figure 3. Drawings of an ammonia molecule

a. ***Experimental group students*** *drew a space-filling model or a tetrahedron, both including the non-bonding electron pair.*

b. ***Control group students*** *drew ball-and-stick or space-filling models without the non-bonding electrons.*

Other differences were reveled in drawing of a C_2H_5OH molecule model. Experimental group students were thorough and detailed when drawing 3D molecular models. They showed the tetrahedral angle (109.5^0) and drew atoms in front and behind the central atom. In contrast, most control group students drew the models as if the atoms were connected at 90^0 angles. Experimental group students used size and color to differentiate between the carbon, oxygen, and hydrogen atoms in the molecule. Models that control group students sketched were less meticulous about these aspects.

Question 3 in the pre- and post-tests, which we evaluated in detail, required higher order thinking skills. It tested students' ability to analyze information about six compounds, select the best anaesthetic substance and provide argument for their choice. Given that ether is flammable and chloroform is known to cause liver damage, the students were asked to select the best alternative anaesthetic and provide arguments for their choice.

The focus of our analysis in this question was the level of students' arguments and their ability to transfer between four understanding levels in chemistry: macroscopic, microscopic, symbolic and process. The correct answer should be $CF_3CHClBr$ and is based on experimentation (*35, 36*), which cannot be expected of chemistry students. Therefore, we based our evaluation on the quality as well as the quantity of the arguments provided. Students were expected to refer in their arguments to the substance physical and chemical properties: structural formula, molecular mass, boiling point, AD_{50} (anaesthetic dose), LD_{50} (lethal dose), anaesthetic index, and halogen percentage.

The responses were categorized into three groups: (1) high level arguments, (2) partial or insufficient arguments, and (3) no argument. An example of an experimental group student's response from the post-test follows. Interleaved within the student's response in italics are our interpretations of the transformations between the four understanding levels.

"$CF_3CH_2CF_3$ *is a good possibility…*" – reference to the symbol level.

"Due to its high boiling point, it will not evaporate in room temperature or in the patient's body. It can be injected in low concentration (we do not need a lot of the substance). Its lethal dose is very low. On the other hand, its anesthetic index is high…"– reference to the macro and micro levels.

"Also, since its halogen percentage is high, there is little chance that the carbon compound will burn when mixed with air." – reference to transfer from the micro (*halogen percentage)* to the process (*will burn*) level.

This well-founded response was categorized as being at the high level. Conversely, a post-test example of a partial, insufficient response, given by a control group student, was: "$CF_3CH_2CF_3$ *is best because the anesthetic index is the highest."*

Analyzing the students score in this question we found a significant difference between the experimental and control grads ($F = 31.08$, $p < 0.001$)

In the pre-test, 65% of both research group students provided no argument whatsoever to support their choice and the remaining responses contained partial or insufficient arguments. As Figure 4 shows, in the post-test the two research groups differed in their argument level.

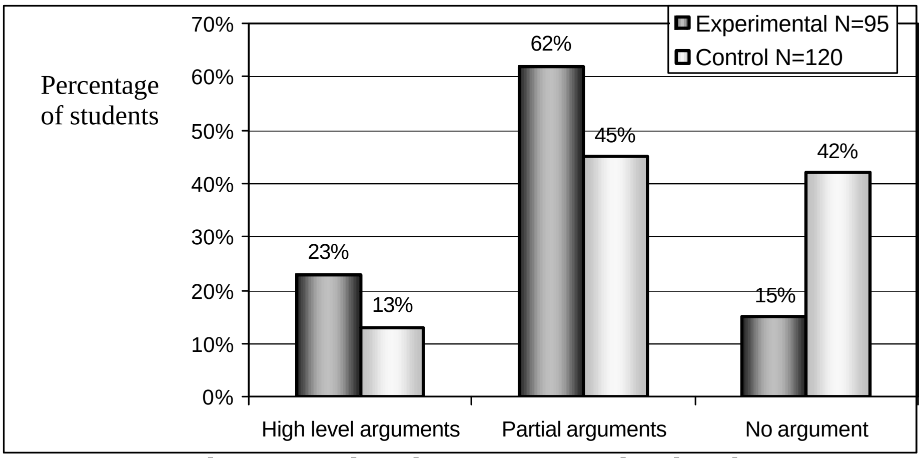


Figure 4. Experimental vs. control students' argument level in the post-test

The percentage of students who provided high level arguments in the experimental group was nearly twice as much as that of their control group peers, while for partial arguments it was 1.4 times as much. Conversely, the percentage of students who gave no argument in the experimental group was one third of the corresponding percentage in the control group. As these results show, experimental students demonstrated better argumentation skills as well as better ability to transfer between the four chemistry understanding levels.

One limitation of our research is that the experimental students were not chosen randomly but based on their willingness to take on the extra project. This may indicate that they were inclined to spend the extra effort and time required, some in order to achieve a higher grade and others because they were more motivated.

Discussion and Summary

As Bunce and Robinson (*37*) have noted, the chemical education community encompasses three intertwined activities: instruction, practice, and research. Many of the chemical educators are involved in at least two of these activities. Indeed, our study was feasible thanks to collaboration among chemistry and chemical education faculty and instructors. We have been actively engaged in Web-based instruction, practicing with chemistry undergraduate and graduate students. One author investigates three-dimensional structures of biological macromolecules (*38*, *39*), while the others study learning processes that employ computerized molecular modeling (*2*, *8*, *9*, *11*).

Based on students' interviews and our observations in class, the use of the Web as a source of a variety of molecular modeling software, inspired students in our research, as well as in the research described in (*40*), and created an enthusiastic learning environment. We found that students were in favor of Web-based chemistry courses despite the fact that chemistry faculty had various reservations as to their readiness to apply IT-enhanced teaching in their classroom. Students noted that access to Web-based learning materials and assignments was valuable, as it contributed to their learning experience. In the interviews with students during their work on the project, some indicated that they had started the project (and the course in general) with low motivation and gained motivation to study chemistry as a result of working on the project. It thus appears that the project enhanced students' motivation to study chemistry.

Incorporating Web-based assignments and computerized molecular modeling into the chemistry courses has been found to foster understanding of molecular 3-D structure and related properties (*9, 11, 15*). Williamson and Abraham (*31*) found that engaging in dynamic animations of molecules promote deeper encoding of information than that of static pictures. Our research aimed at improving and promoting higher education chemistry teaching through the development, implementation, and assessment of a Web-based freshmen general chemistry course. Our findings indicate that IT-enhanced teaching positively affects students' achievements provided the students are actively engaged in constructing computerized models of molecules. These results are in line with the findings of Kantardjieff et al. (*40*), and of Donovan and Nakhleh (*15*). Kantardjieff et al. found that sophomore students, who engaged in exploration activities, learned to apply modern chemistry software packages, and acquired skills needed to become practitioners of their discipline. Donovan and Nakhleh concluded that the Web site used in their general chemistry course was instrumental in visualizing and understanding chemistry.

The level of students' engagement with Web-based activities depended on the assignments they were required to deliver as part of the course. In study (*15*), students could succeed in the course without using the Web and in fact, low academic level students accessed the Web more frequently than high academic level ones because they viewed it as a supplementary source of help. In our study, all the students who elected to undertake the Web-based computerized molecular modeling project (the experimental group) performed significantly better in both the post-test and the final examination than those who elected not to carry out the project (the control group). We found that low academic level students of the experimental group made the greatest progress in chemistry understanding.

Experimental students at all academic levels applied transformations from one-dimensional molecule representation, to two- and three-dimensional representations, and vice versa better than their control group peers. The differences in drawings of molecular models between the two research groups indicated that experimental group students understood the geometric structure of molecules and their related physical and chemical properties better than the control group students.

Harrison and Treagust (*41*) noted that students who were encouraged to use multiple models demonstrated understandings of particles and their interactions better than students who searched for one best model. In our research, the experimental students carried out an individualized project using computerized molecular modeling software to represent a complex molecule in three model types, compute its molecular weight and construct hybridization and electrical charge distribution for each of the carbon atoms in the molecule. As a result of their interaction with the software to execute their project, they were better prepared to argue for selecting an appropriate substance for a particular purpose and could carry out transformation between the four levels of understanding in chemistry.

While other means, such as plastic models and extra recitations hours, might have replaced the Web-based learning environment, in the long run, technology-rich environment is less labor-intensive and provides for asynchronous, interactive learning. Indeed, our Web-based chemistry course has proven to be an effective means to foster freshmen learning and should therefore be further practiced and investigated with the objective of establishing the elements that contribute the most to enhancing students' higher order thinking.

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