Chemical Education Research

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A Web-Based Chemistry Course as a Means To Foster Freshmen Learning

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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 aided by three-dimensional 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. This new medium facilitates communication among teachers and students worldwide and allows transfer of information with unprecedented speed and freedom from time and geographical barriers. 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)*.

While teaching the properties of substances and how they react, chemistry educators identified three levels of understanding: macroscopic, microscopic, symbolic *(26–29)*. Nakhleh and Krajcik *(5)* argued that there are four interconnected representational systems: the macroscopic system, microscopic system, symbolic system, and the algebraic system, in which the relationships of matter are presented and manipulated using formulas and graphs. Instead of the algebraic system, Dori and Hameiri *(30)* suggested another 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 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 course Web site included the following elements:

- Weekly problem sets, for which solutions were provided a week later
- Hyperlinks to Web sites that provide information about topics in chemistry that are relevant to the course, including historical and philosophical background
- Hyperlinks to sites that provide access to free computerized molecular modeling software
- An electronic forum that enables students to pose questions and instructors to answer them
- An optional, individual CMM project

Research Objective and Questions

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

- How did chemistry faculty, teaching assistants, and students view Web-based teaching and learning?
- How did the individual optional computerized molecular modeling project affect the students' learning outcomes?

Research Population

The research population consisted of seven chemistry faculty and six chemistry teaching assistants, 53 students who participated in a survey, and 215 students who participated in three Web-based chemistry courses. 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. The average entry-level grade of the experimental group students was 84.02 (s = 6.02), while that of the control group students was 82.63 (s = 6.18). We found no significant difference between the two research groups regarding their entry-level grades (t = 1.65, $p < 0.10$). We also compared the two research groups in terms of their prior knowledge in chemistry. We found that 36.8% of the experimental students and 39.2% of the control students had prior knowledge in chemistry. No significant difference between the two groups in prior knowledge in chemistry was found ($\chi^2 = 0.12$, $p < 0.72$).

Research Design

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 the individual project, which involved an intensive use of the Web and CMM, and credited them with an extra five points for their final grade. The project was handed out during the sixth week, after the students had studied chemical bonding and molecular orbitals, and was due during the last week of the semester.

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, vitamin B, vitamin 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 its daily use or applications.

Students carried out the project voluntarily in their free time in addition to the regular course load. Some students noted that the project required five hours, while others said it took them over 10 hours due to technical difficulties. Many of the experimental students whom we talked with complained that the project was complex and time-consuming. 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.

In the interviews, faculty and teaching assistants were asked the following two open-ended questions:

1. Have you used the Web or Information Technology (IT) for teaching general chemistry courses?
2. How do you feel about the use of computers and the Internet in teaching and learning chemistry?

In the students' survey, which investigated their opinions regarding the use of the Web as a learning environment, students were asked: "Would you like to study chemistry in a Web-based and Computerized Molecular Modeling environment? If so, specify the preferred chemistry topics."

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, grades on entry, and final examination scores. The pre- and post-tests were similar and included three questions. They were administered during the first and last week of the 14-week semester, respec-

2. Fill in the table below with the type of molecular representation indicated by the column heading.

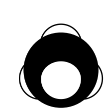
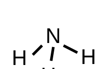
Molecular Compound	Molecular Formula	Structural Formula	Spatial Structure	Hybridization (sp, sp^2, sp^3)	Model
Ethanol	C_2H_6O				
				sp^3	
			Triangular Pyramid		

Figure 1. Question 2 of the pre- and post-tests, designed to assess students' ability to make transformations from one-dimensional molecular representation, to two- and three-dimensional representations, and vice versa.

tively. The test questions included images of models that appear in general chemistry textbooks. While the questions did not relate directly to CMM techniques, we assumed that students actively engaged in building computerized models would perform better in solving these questions than students who only saw similar models in lecture or in textbooks.

The pre- and post-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 (Figure 1) investigated students' ability to apply transformation from 1-D molecular representation to 2-D and 3-D representations, and vice versa. This question was developed and validated by Dori and Barak *(11)*.

The third question, developed and validated by Reid *(35, 36)* and presented in Figure 2, investigated students' ability to answer a higher-order thinking skills question. The pre- and post-test questions were also validated by three chemistry experts.

The final examination[1] was written by the chemistry instructor, based on prior examinations, which were developed by generations of experienced faculty. Two chemical educators established the content validity of this examination. The examination contained open-ended questions regarding atomic theory, stoichiometry, property of gases, liquids, and solids, chemical equilibrium, chemical thermodynamics, chemical kinetics, chemical bonding, and molecular orbitals. The reliability of this examination was based on the observation that its scores were consistent with those of prior semesters.

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 habits.*
- *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 pre-

3. The table below provides information about six compounds. The first two are ether and chloroform—both of which have been known for a long time. The remaining four are compounds that might be useful anaesthetics. Ether has a tendency to catch fire and chloroform is known to cause liver damage. Based on the data below, choose the best anaesthetics to replace ether and chloroform. Add a detailed argument for your choice.

Compound	Formula Mass	Boiling Point / °C	Anesthetic Dose (AD_{50})	Lethal Dose (LD_{50})	Anesthetic Index	Halogen / %
$CH_3CH_2OCH_2CH_3$	74	35	3.2	11.2	3.5	0
$CHCl_3$	119.5	61	0.8	2.6	3.3	89
$CHFCl_2$	103	9	3.1	6.4	2.1	87
$CF_3CHClBr$	197.5	50	0.9	3.6	4.0	87
$CF_3CH_2\ CF_3$	152	–1	11	44	4.0	75
$CF_3CH_2OCH_2CH_3$	128	50	4.0	8.0	2.0	46

Figure 2. Question 3 of the pre- and post-tests, designed to assess students' ability to answer a higher-order thinking skills question.

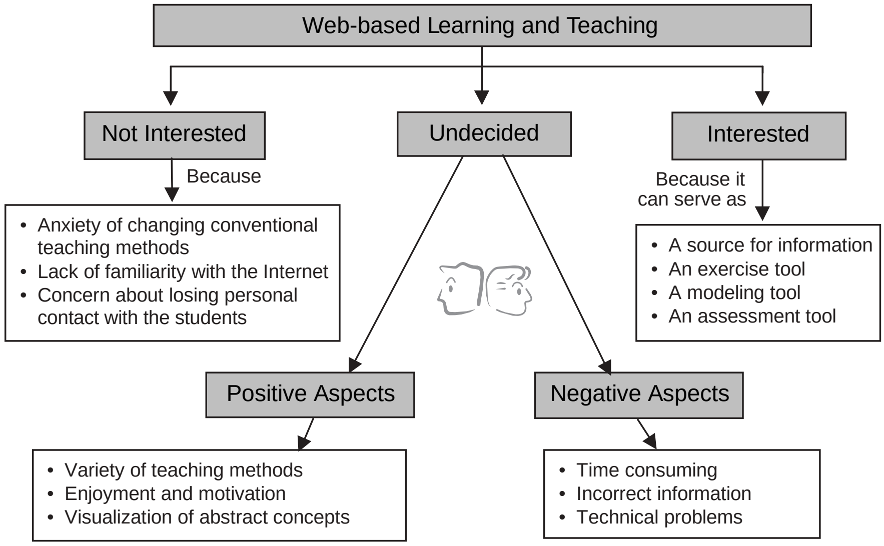


Figure 3. Instructors' attitudes towards learning and teaching chemistry in a Web-based learning environment.

sented 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. Figure 3 summarizes the lecturers and TA's attitudes towards learning and teaching in a Web-based environment.

Analyzing the students' survey, we found that 95% responded positively to the open-ended question, "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 majority of students were interested in learning chemistry in a Web-based environment. Figure 4 shows the distribution of chemistry topics that students would like to study in this type of 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)*.

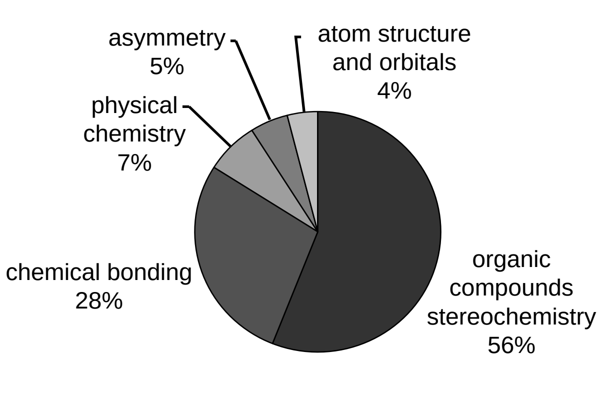


Figure 4. Chemistry topics that students would like to study in a Web-based environment.

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 5. 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 teaching assistants and ask them questions. The individual project required intensive use of the Web and CMM software. Figure 6 shows an example of a 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 1 presents ANCOVA of the post-test and final examination scores, showing 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 relative to their control group peers.

To further test this assumption, we divided the students according to their pre-test scores into three academic levels: high, intermediate, and low, such that each group included about one third of the research population. High academic

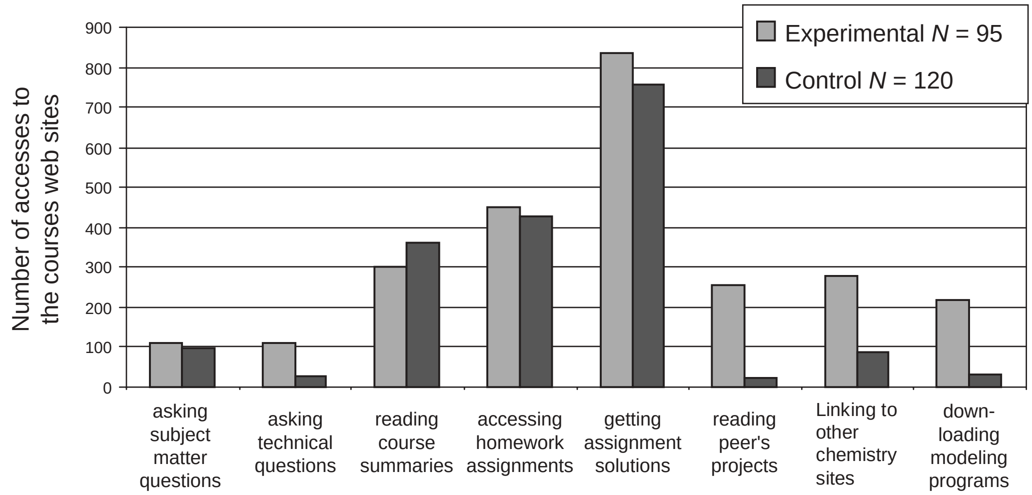


Figure 5. Comparison between control and experimental groups of frequency and purpose of accessing the course's Web sites.

level students were defined as those who received scores in the range of 41–80 (nobody scored more than 80 in the pre-test). Intermediate academic level students received scores in the range of 21–40, and low academic level students scored in the range of 0–20.

We examined the students' progress at each academic level and compared between control and experimental groups. The results are presented in Table 3.

Both research groups have advanced in their chemistry understanding during the 14-week course, yet as Table 3 shows, the experimental group advanced more than the control group at each academic level. We carried out a Post Hoc Scheffe test to establish whether there is a significant difference between the relative improvements[2] of the research groups at each academic level. We found that the relative improvement of the experimental students at the high academic level was significantly higher ($p < 0.001$) than their control group peers. Likewise, the relative improvement of the experimental students at the intermediate academic level was also significantly higher ($p < 0.05$) than their control counterparts. The low academic level students of the experimental group made the greatest progress, as expressed by their net gain. However, the experimental low academic level students had a higher starting point than the control low academic level students (Table 2). Therefore, the difference in the relative improvement between the two low academic level groups was not significance ($p < 0.10$).

We analyzed students' responses to each of two questions individually. Question 2, presented in Figure 1, tested students' ability to apply transformations to and from one-dimensional molecule representation to two- and three-dimensional representations. The scores range was 0–48. The results of the experimental and control groups were = 40.32, s = 9.24 and = 31.20, s = 12.84, respectively.

To analyze the effect of the CMM project on students' ability to apply transformations, and examine whether there is a difference between genders, we perform an analysis of covariance (ANCOVA), using the pre-test scores as the covariant (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). No significant difference between the genders was found. The interaction between learning method and gender was found to be borderline significant. Experimental males received the highest scores (= 41.14, s = 13.07) compared with experimental females (= 38.83, s = 13.96), control male (= 30.21, s = 18.91) and control females (= 32.17, s = 17.91).

Analyzing the models students had drawn in question 2, we found that the experimental group students filled 73% of the blank cells with models (Figure 1), while the control group students filled 51% of the blank cells. Students' drawings of NH_3 and CH_3CH_2OH molecule models in Figures 7 and 8 depict typical differences between the two research groups. The 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 7 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.

Other differences are shown in Figure 8, which depicts drawing of a C_2H_5OH molecule model. Three-dimensional molecular models drawn by experimental group students were thorough and detailed. They showed the tetrahedral angle (109.5°) 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° 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 anesthetic substance and provide argument for that choice (Figure 1). Given that ether is flammable and chloroform is known to cause liver damage, the students were asked to select the best alternative anesthetic 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's physical and chemical properties: structural formula, molecular mass, boiling point, AD_{50} (anesthetic dose), LD_{50} (lethal dose), anesthetic 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 (in parantheses) 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*

Table 2. Analysis of Covariance of the Post-Test and the Final Examination Scores

Dependent Variable	Research group	*N*	X	*s*	*F* Value	p Value
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	18.9	5.19	<0.02
	Control	120	62.02	25.23		

Table 3. Means and Standard Deviations of Both Research Groups by Academic Levels

Research Group			Pre-Test		Post-Test	
	Academic Level	*N*	X	SD	X	SD
Experimental	High	31	52.39	8.85	84.64	10.76
N = 95	Intermediate	27	29.37	5.58	70.66	13.76
	Low	37	12.05	7.55	64.05	19.22
Control	High	42	52.52	8.75	61.26	20.32
N = 120	Intermediate	42	31.19	5.21	53.67	16.78
	Low	36	8.39	7.2	44.33	17.45

Table 4. Analysis of Covariance of the Transformation Abilities between Three, Two, and One Molecule Representation Modes in the Post-Test

Source of Variance	SS	DF	MS	*F* Value	*p* Value
Learning Method (integrating the CMM project)	86.61	1	86.61	26.68	<0.001
Gender	0.22	1	0.22	0.07	n.s.
Interaction between Learning Method and Gender	9.97	1	9.97	3.07	<0.08

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 macroscopic and microscopic 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, stated:

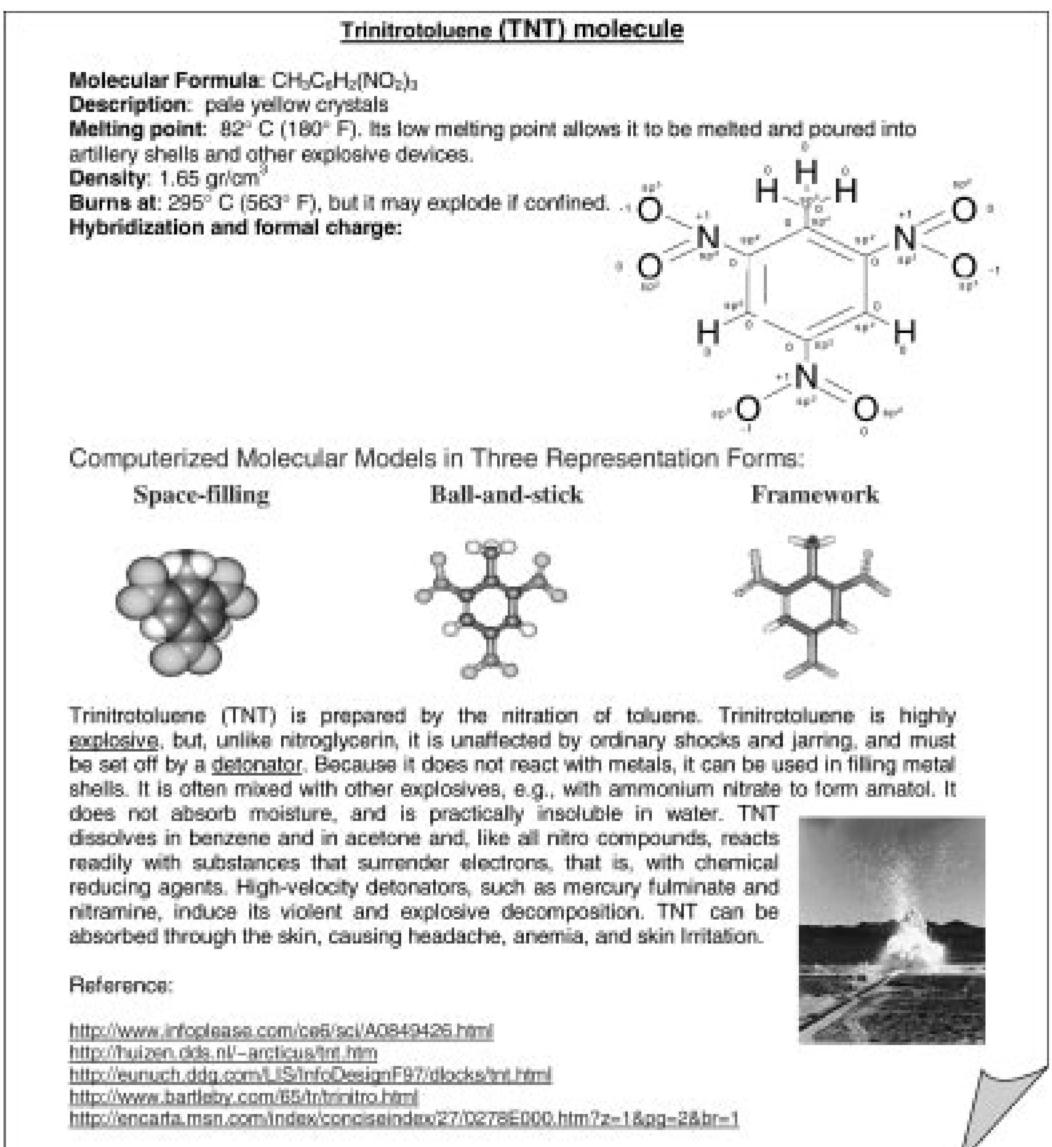
- *$CF_3CH_2CF_3$ is best because the anesthetic index is the highest.*

Analyzing the students' scores for this question we found a significant difference between the experimental and control grades ($F = 31.08$, $p < 0.001$).

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 9 shows, in the post-test the two research groups differed in their argument level.

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



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. It does not absorb moisture, and is practically insoluble in water. TNT dissolves in benzene and in acetone and, like all nitro compounds, reacts readily with substances that surrender electrons, that is, with chemical reducing agents. High-velocity detonators, such as mercury fulminate and nitramine, induce its violent and explosive decomposition. TNT can be absorbed through the skin, causing headache, anemia, and skin irritation.

Reference:

http://www.infoplease.com/ce6/sci/A0849426.html
http://huizen.dds.nl/~arcticus/tnt.htm
http://eunuch.ddg.com/LIS/InfoDesignF97/dlocks/tnt.html
http://www.bartleby.com/65/tr/trinitro.html
http://encarta.msn.com/index/conciseindex/27/0278E000.htm?z=1&pg=2&br=1

Figure 6. A student's CMM Project.

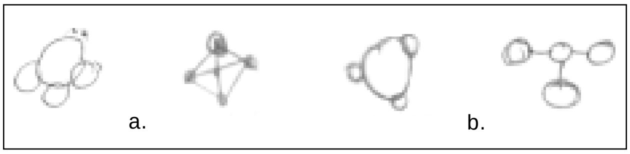


Figure 7. Drawings of an ammonia molecule showing (a) a space-filling model or a tetrahedron, both including the non-bonding electron pair, drawn by experimental group students, and (b) ball-and-stick or space-filling models without the non-bonding electrons, drawn by control group students.

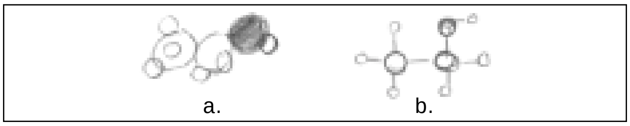


Figure 8. Drawings of an ethanol molecule showing (a) a space-filling model (by an experimental group student), and (b) a ball-and-stick model by a control group student. In (a) some atoms are in front of the central atom and others behind; atoms around the carbon are arranged in tetrahedral structures; gray color represents the oxygen atom. In (b) atoms connect at 90° angles and are colorless.

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 three-dimensional 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 that 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 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 understand-

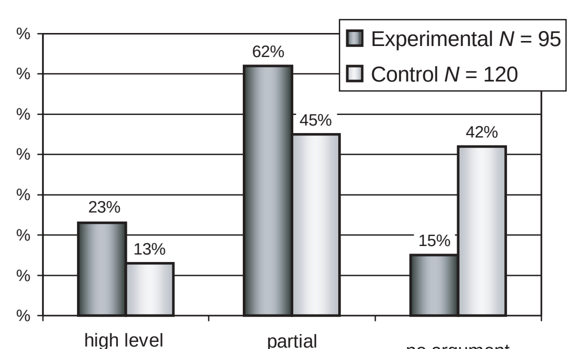


Figure 9. Graph showing the argument level demonstrated in the post-test by experimental group students versus control group students.

ings 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, a technology-rich environment is less labor-intensive in the long run 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.

Notes

1. The questions are posted in Hebrew on the Technion Web site: *http://Web_site_address_here* (accessed Jul 2003).

2. Computed according to Hake, [R. R. *American Journal of Physics* 1998, *66*, 64?].

Literature Cited

1. DeBard, R.; Guidera, S. *J. Educ. Tech. Systems* 2000, *28*, 219–230.
2. Dori, Y. J. *J. Sci. Educ. and Tech. {Systems?}* 1995, *4*, 163–170.
3. Lazarowitz, R.; Tamir, P. In Gable, D. L. (Ed.), *Handbook of Research on Science Teaching and Learning;* Macmillan Publishing Company: New York, 1994; pp 94–128.
4. Nakhleh, M. B. *J. Comp. in Math. Sci. Teach.* 1994, 13, 368–381.
5. Nakhleh, M. B.; Krajcik, J. S. *J. Res. Sci. Teach.* 1994, 31, 1077–1096.
6. Baker, R. S.; Talley, H. L. *J. Res. Sci. Teach.* 1974, 11, 95–97.
7. Eliot, J. K.; Hauptmam, A. *Studies in Sci. Educ.* 1981, 8, 45–66.
8. Dori, Y. J.; Barak, M. Computerized Molecular Modeling as a Collaborative Learning Environment. In *Proceedings of the Computer Support for Collaborative Learning (CSCL) 1999 Conference* (Dec. 12–15, 1999); Hoadley, C.; Roschelle, J., Eds.; Stanford University: Palo Alto, CA, 1999; pp 142–150.
9. Barnea, N.; Dori, Y. J. *J. Sci. Educ. and Tech.* 1999, *8*, 257–271.
10. Copolo, C. F.; Hounsell, P. B. *J. Sci. Educ. and Tech.* 1995, *4*, 295–305.
11. Dori, Y. J.; Barak, M. *Educ. Tech. and Soc.* 2001, *4*, 61–74. *http://ifets.ieee.org/periodical/vol_1_2001/dori.pdf* (accessed Jul 2003).
12. Merlic, C. A.; Fam, B. C.; Miller, M. M. *J. Chem. Educ.* 2001, *78*, 118–120.
13. McGrowan, C.; Sendall, P. *J. Chem. Educ.* 1997, *74*, 391.
14. Waldow, D. A.; Fryhle, C. B.; Brock, J. C. *J. Chem. Educ.* 1997, *74*, 441–442.
15. Donovan, W. J.; Nakhleh, M. B. *J. Chem. Educ.* 2001, *78*, 975–980.
16. Foust, R. D.; Cruickshank, B.; Stringer, M.; Olander, J.; Curley, A. O. *The Chem. Educ.* 1999, *4*, 108–111. *http://journals.springer-ny.com/chedr* (accessed Jul 2003).
17. Lui, D.; Walter, J.; Brooks, D. *J. Chem. Educ.* 1998, *75*, 123–125.
18. Kozma, R. B.; Russell, J. *J. Res. Sci. Teach.* 1997, *34*, 949–968.
19. Glaser, R. E.; Poole, M. J. *J. Chem. Educ.* 1999, *76*, 699–703.
20. Gordin, D. N.; Gomez, L. M.; Pea, R. D.; Fishman, B. J. *J. Comp. Mediated Commun.* 1997, *2*. *http://cwis.usc.edu/dept/annenberg/vol2/issue3/gordin.html#rfoot1* (accessed Jul 2003).
21. Hughes, C.; Hewson, L. *Educ. Tech.* 1998, July-August 48–55.
22. Judd, C. S. *J. Chem. Educ.* 2000, *77*, 808.
23. Paulisse, K. W; Polik, W. F. *J. Chem. Educ.* 1999, *76*, 704–708.
24. Schwartz, A. T.; Bunce, D. M.; Silberman, R. G.; Stanitski, C. L.; Stratton, W. J.; Zipp, A. P. *J. Chem. Educ.* 1994, *71*, 1041.
25. Smith, S. G.; Stovall, I. K. *J. Chem. Educ.* 1996, *73*, 911–915.
26. Gabel, D. L. In *International Handbook of Science Education;* Fraser, B.; Tobin, K., Eds.; London: Kluwer Academic Pub., 1998; pp 233–248.
27. Gabel, D.L.; Bunce, D.M. In *Handbook of Research on Science Teaching and Learning;* Gable, D. L., Ed.; Macmillan: New York, 1994; pp 301–326.
28. Herron, J. D. *The Chemistry Classroom: Formulas for Successful Teaching;* American Chemical Society: Washington, DC, 1996.
29. Johnstone, A. H. *J. of Comp. Assisted Learn.* 1991, *7*, 75–83.
30. Dori, Y. J.; Hameiri, M. *Int. J. Sci. Educ.* 1998, *20*, 317–333.
31. Williamson, V. M.; Abraham, M. R. *J. Res. Sci. Teach.* 1995, *32*, 521–534.
32. Harrison, A. G.; Treagust, D. F. *Sci. Educ.* 1996, *80*, 509–534.
33. WEBLAB. *http://www.msi.com/life/products/weblab/viewer/index.html* [URL is not valid: provide a new one or remove.]
34. ISIS DRAW. *http://www.mdli.com/downloads/isis.draw/isisdrawreg.html* (accessed Jul 2003).
35. Reid, N. *Chem. Educ.: Res. and Prac. in Europe* 2000, *1*, 381–392. *http://www.uoi.gr/cerp/2000_October/09.html* (accessed Jul 2003).
36. Reid, N. Bringing work experience to undergraduates. *Education in Chemistry* 36 (1), 23–24.
37. Bunce, D. M.; Robinson, W. R. *J. Chem. Educ.* 1997, *74*, 1076.
38. Adir, N. *Acta Crystalographica* 1999, *D55*, 891–894.
39. Asojo, O.; Friedman, J.; Adir, N.; Belakhov, V.; Shoham, Y.; Baasov, T. *Biochem.* 2001, *40*, 6326–6334.
40. Kantardjieff, K. A.; Hardinger, S. A.; Van Willis, W. *J. Chem. Educ.* 1999, *76*, 694–697.
41. Harrison, A. G.; Treagust, D. F. *Sci. Educ.* 2000, *84*, 352–381.