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Enhancing Students' Understanding of the Concept of *Chemical Bonding* by Using Activities Provided on an Interactive Website

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Abstract: This study investigated the effectiveness of a web-based learning environment in enhancing 10th grade high-school students' understanding of the concept of *chemical bonding*. Two groups participated in this study: an experimental group ($N = 161$) and a comparison one ($N = 93$). The teachers in the experimental group were asked to implement four activities taken from a website, all dealing with the concept of *chemical bonding*. Computer-based visual models are utilized in all the activities in order to demonstrate bonding and the structure of matter, and are based on student-centered learning. The study incorporated both quantitative and qualitative research. The quantitative research consisted of achievement questionnaires administered to both the experimental and comparison groups. In contrast, the qualitative research included observations and interviews of students and teachers. Importantly, we found that the experimental group outperformed the comparison group significantly, in the achievement post-test, which examines students' understanding of the concept of *chemical bonding*. These results led us to conclude that the web-based learning activities which integrated visualization tools with active and cooperative learning strategies provided students with opportunities to construct their knowledge regarding the concept of *chemical bonding*. © 2008 Wiley Periodicals, Inc. J Res Sci Teach 46: 289–310, 2009

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We assert that web-based learning facilitates the use of a diverse range of visual tools that demonstrate abstract scientific phenomena. Many studies (Ardac & Akaygun, 2004; Barnea & Dori, 2000; Sanger & Badger, 2001; Stieff, 2005; Tversky & Morrison, 2002; Wu, Krajcik, & Soloway, 2001) dealing with using computer-based visual models found that students benefit from this type of representation. Hence, incorporating such interactive simulations is effective for both students and teachers in strengthening the learning and teaching process. In addition, when the study was conducted, it was assumed that when the website activities are professionally designed, they have the potential to promote collaborative and student-centered learning. A web-based environment in which the students are provided with clearly defined and focused activities promotes an environment in which the students become active participants in the learning process, assisted by their teachers and peers. Active learning is defined as learning that strengthens student involvement in the learning process and has had a positive impact on student attitudes and achievements (Bonwell & Eison, 1991; Felder & Brent, 2003; Moore, 1989). Several very significant interactions occur when students are engaged in web-based activities while they work in small groups: interactions take place between the student and the learning materials, between the students themselves, and between the students and their teacher. It was suggested in the literature that social aspects are important components of learning processes (Johnson, Johnson, & Smith, 1998a,b; Mayer, 1999; Semple, 2000). We believe that all these lead to effective, more meaningful learning and to a more in-depth understanding of the science topics being studied.

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The main goal of this study was to evaluate the educational effectiveness of a web-based learning environment regarding 10th grade students' understanding of the concept of *chemical bonding*. More specifically, the research question is as follows:

How did the web-based activities contribute to students' better understanding the structure of matter and the concept of *chemical bonding*?

The uniqueness of this study is that it contains several aspects of learning: (1) the contribution of the visualized computerized models to the students' comprehension of the material; (2) active learning in which the student is in the center of learning; and (3) cooperative learning while performing various activities. This study investigates the effectiveness of web-based learning centered on visualization, in strengthening student involvement in the learning process. In addition, the contribution of web-based learning to students' understanding of the concept of *chemical bonding* is discussed along with the accompanying implications.

Theoretical Framework

The Web-Based Learning Environment

Web-based technology, which has made huge strides over the past decade, is slowly but steadily gaining momentum in education and learning worldwide. Many studies have noted the benefits of web-based learning and its vast potential to empower learning and teaching (Carpi, 2001; Clark, 2004; Linn, Clark, & Slotta, 2003; Mistler-Jackson & Songer, 2000). For example, Linn et al. (2003), in their study of Web-Based Inquiry Science Environment (WISE) projects, found that when students and teachers participate in a series of WISE projects, they have the opportunity to gain a deeper and more comprehensive understanding of the inquiry process. Also, Mistler-Jackson and Songer (2000) found that carefully and well-designed network-based science projects have the potential to enhance student's motivation, and students discover what it means to learn and engage in scientific activities. More specifically, aligned with the present study, several investigators (summarized by Clark, 2004) noted the importance of integrating computer-based visualizations into learning. Clark presented several studies that demonstrated that visualizations help students to focus on ideas within the realm of the curriculum. Kozma and Russell (2005) suggested that molecular models, simulations, and animations could aid in studying chemistry in general and in better understanding the concept of *chemical bonding* in particular. They also found that web-based interactive animations helped students understand difficult and abstract concept associated with equilibrium, electrochemistry, and chemical solutions, and aided students' understanding of molecular and dynamic concepts in laboratory experiments. More recently Marbach-Ad, Rotbain, and Stavy (2008) concluded from their study that it is advisable to use computer animations in molecular genetics, especially when teaching about dynamic processes.

It is suggested that the use of computers in the teaching of science and technology has many advantages including the ability to use simulations, graphs, and to demonstrate models at the macroscopic and microscopic levels. Barak and Dori (2005) found that the use of computer-based models helped promote students' understanding of chemistry at four levels: the macroscopic, microscopic, symbolic, and chemical process levels. Furthermore, they found that the computer-based visual models helped novice students understand chemical concepts, theories, and molecular structures. Moreover, Ardac and Akaygun (2005) found that students who learned with the aid of dynamic computer-based models outperformed their peers (who had no such experience) regarding molecular representations (using drawings) and their understanding of the structure of matter.

Although the literature is relatively rich in evidence regarding the benefits of web-based learning in science classrooms, others (Wallace, Kupperman, Krajcik, & Soloway, 2000; Winebrener, 1997) remain pessimistic regarding its application as an instructional tool. For example, Winebrener claimed that students are mislead by viewing falsified information posted on the web, and are confused by the varying forms of navigation. In addition, the students were frustrated due to their inability to locate specific information easily. Similar findings were also found in studies conducted by Wallace et al. (2000), and by Hoffman, Wu, Krajcik, and Soloway (2003), which indicated difficulties with inquiry learning through Internet-based resources. Also, Waight and Abd-El-Khalich (2007) found that the use of computer technology restricted rather promoted inquiry in 6th grade science classrooms. They claimed that it is naïve to assume that computer use would foster inquiry in any substantial way. Research has also shown that it is quite difficult to integrate technology in order to advance and strengthen the learning process. However, the majority of researchers in this area continue to believe that dynamic media has great potential for both teaching and learning alike (Hegarty, 2004).

Constructing Knowledge in a Web-Based Learning Environment

There is widespread agreement within the education community that meaningful learning is a process in which the student actively collects, organizes, and processes information as it becomes knowledge (Salomon, 2000). Bransford, Brown, and Cocking (2000) suggested that active learning requires the students to read, write, discuss, and solve problems as well as get involved in tasks that demand high-level thinking such as analysis, synthesis, and evaluation.

Educational constructivism emphasizes the learner rather than the instructor; thus, the students take responsibility for the learning process (Brooks & Brooks, 1993). Constructivist learning theory suggests that students use ideas and construct knowledge already in their minds to make sense of their experiences. Matthews (2000) suggested that constructivism is undoubtedly one of the major theoretical constructs that influences contemporary science and mathematics education. Fensham (1992) claimed that "the most conspicuous psychological influence on curriculum thinking in science since 1980 has been the constructivist view of learning."

Social constructivism stresses that learning is a social activity in which learners are involved in constructing knowledge through discussions and negotiations with peers. While learning in this way, students can identify and articulate their own ideas, exchange views, and reflect on those of other students (McRobbie & Tobin, 1997; Prawat, 1993; Solomon, 1987). In the social constructivist approach, cooperative learning is encouraged (Eshet & Hammer, 2006). Students are encouraged to assume a more active role in their learning, to explain their ideas to one another, to discuss disagreements, and to cooperate in solving complex problems, while teachers participate in the design of these contexts and act as a facilitator of this and similar kinds of activity (Resnick, Salmon, Zeitz, & Wathen, 1993). This is congruent with the study of Krystyniak and Heikkinen (2007), which found that students employed science process skills, and engaged in higher-order thinking during laboratory activities, while the teacher changed his behavior from deliverer of information to a facilitator.

Students' Difficulties in Understanding the Concept of Chemical Bonding

The difficulties students encounter in understanding the concept of *chemical bonding* have been the subject of a great deal of research. Based on the literature, the abstract concept of *chemical bonding* is considered by teachers, students, and chemical educators to be a very difficult and complicated concept (Gabel, 1996; Levy Nahum, Hofstein, Mamlok-Naaman, & Bar-Dov, 2004; Taber, 2002). More specifically, atomic structure, the particulate nature of matter, the molecule, and the chemical bond are considered abstract concepts. Students' misconceptions regarding these concepts are based on the fact that they live and operate within macroscopic world of matter and do not easily follow shifts between macroscopic and sub-macroscopic levels (Gabel, 1996; Harrison & Treagust, 2000). Consequently, they tend to build themselves alternative conceptions and nonscientific mental models (Taber, 2002). *Chemical bonding* is a concept in which understanding is developed by using models through which the students are expected to interpret a disparate range of symbolic representations (Taber & Coll, 2002). Many teachers use models to help students understand this concept, sometimes introducing more problems because of incorrect use of models and lack of discussion about the limitations of the models (Justi & Gilbert, 2002; Lunetta & Hofstein, 1991). In addition, very often teachers use only one type of model (such as ball-and-stick in chemistry), thereby eliminating student acquaintance with the diversity of other models, and leaving students with only a partial grasp of the model or a complete misunderstanding of it (Barnea & Dori, 2000).

A thorough analysis of students' answers during a 12-year period was conducted by analyzing final examinations (matriculation) that were administered centrally by the government. Our aim was to analyze their response (answers) to questions related to bonding and the structure of matter. It was found that students could not indicate the specific particles that compose the matter, and they had many difficulties in understanding the type of chemical bond between the particles in the ionic, molecular, and metal structures.

The findings indicated that the subject is problematic and that the same misconceptions are repeated year after year (for more details, see Levy Nahum et al., 2004).

The Study

The Rationale and Development of the Website

The current research study is an attempt to investigate the educational effectiveness of an instructional tool in order to help students overcome their difficulties in understanding the concept of *chemical bonding* (as cited in the literature above). In developing the web-based learning environment, three aspects were considered: (1) The students are exposed to varied visualized dynamic models of structures of matter and *chemical bonding* to demonstrate the abstract concepts of *chemical bonding*. (2) The web-based activities developed were based on students' active learning. (3) The students interact collaboratively in small groups on the web-based activities. The web-based learning environment that was developed for this study utilizes the potential and the advantages of the electronic media efficiently. We have tried to incorporate all the above principles into this learning environment to achieve meaningful learning.

A website was developed entitled: "*Chemistry and the Chemical Industry in the Service of Mankind*" (is in Hebrew only); its URL is: http://stwww.weizmann.ac.il/g-chem/learnchem. This website augments most of the high-school curriculum and contains a wide range of activities on the topics studied in high-school chemistry; more specifically, it includes databases on chemical substances and chemical industrial plants, a glossary, picture galleries, documents, and a search engine (see also a more detailed description in Kesner, Frailich, & Hofstein, 2003). The goal was to plan and construct a site that will be based on information technology principles as well as be dynamic, appealing, up-to-date, user-friendly, and interactive. More specific goals in setting up the site were (1) to enrich chemistry studies in terms of the learning materials and the pedagogical and didactic tools used, and to increase student involvement in the learning process; (2) to utilize web-based resources to demonstrate and promote understanding of abstract phenomena by means of varied types of representations, such as computer-based models, animations, three-dimensional images, video clips and applets; (3) to create a web-based learning environment as a teacher's aid in high-school chemistry lessons; (4) to supply sources of enrichment beyond the curriculum for interested students; (5) to emphasize the relevance of chemistry in everyday life (to include industrial chemistry) in order to boost student interest and motivation; and (6) to utilize electronic communications such as email and Internet group discussions (forums) between teachers and students, between students and experts, and between students and their peers in order to strengthen and widen the learning process, and to vary the chemistry classroom learning environment.

In the present study we focused on activities (from the website), all of which deal with the concept of *chemical bonding*, for the following reasons: (1) *Chemical bonding* is a key concept that is taught in 10th grade chemistry in high school. It provides the basis for many chemistry topics that follow, and (2) *Chemical bonding* topics are very difficult for students with the existing tools (e.g., static models in books, ball-and-stick models), which are insufficient to demonstrate the abstract phenomena associated with this subject. The four activities developed for this study are (1) models of the atomic structure, (2) metals—structure and properties, (3) ionic substances in everyday life and in industry, and (4) molecular substances—structure, properties, and uses. Each of these activities (except for models of atomic structure) consisted of the following four sections:

Section A deals with the structure of substances and is accompanied by visual tools to demonstrate the structure of the substances (metal, ionic, or molecular). This section presents varied computer-based models from different websites. The students are required to interpret them and to explain them in their own words.

Some of the questions accompanying them in the activity "Metals—structure and properties" follow (few examples):

(1) There is a list of websites specifying the structure of metals. Describe, in your own words, the structure of metals and add an illustration.
(2) Choose one of the illustrations and specify what each item in the illustration signifies.
(3) What is a metal bond? Between which particles does a metal bond occur?

Section B deals with the physical properties of substances. In this section, the students received the URLs of various websites containing information about the physical properties of different substances and were asked to complete a table and to record for each substance its melting and boiling point, type of chemical bond, and type of lattice and electrical conductivity, using the information presented on those websites and material taught in the classroom.

Section C deals with the connection between the structure of the substance and its properties. In this section the students were asked to use the information they had acquired in the previous sections of the activity and the prior knowledge that they had achieved in the classroom in order to find the connection between the structure of a substance and its properties, and to give reasons for their answers.

Section D deals with the relevance of chemistry and links substances to everyday life. Web resources were presented that provide information on various substances. The students were asked to choose a substance of interest and to prepare a presentation about it including information such as its properties, its uses in everyday life, and methods of producing it in industry, as well as any other interesting information they found (Frailich, Kesner, & Hofstein, 2007).

The activities that were developed for this study focus on the learning process and guide the students step by step. Students were asked to follow the instructions of each activity and they had to answer precisely the questions they were asked in their own words. Hence, the students must think about the questions, try to understand them, look at the dynamic models (e.g., animations, applets in Section A), and connect them to their previous theoretical studies in class, then formulate and write the answers. In this way, the students take an active part in the learning process, and discuss the answers with their classmates, since they are working in groups. Note that the visualized models used in the activities differ from the static models in books, as presented in Table 1.

Based on Table 1, the students might explore a variety of visualized models on web-based activities more than models presented in a book. This fact will induce students to view a broader and more accurate picture of the structure of matter.

The Research Question

The research question is: How did the web-based activities contribute to students' better understanding the structure of matter and the concept of *chemical bonding*?

Methodology

Research Population

The study consisted of two groups: an experimental group and a comparison group of 10th grade students. Two criteria helped us in selecting the experimental group: (1) schools that had appropriate and relevant technology (i.e., computers and access to the Internet); and (2) teachers that choose voluntarily to integrate the web-based learning environment into chemistry studies. The comparison group was chosen in a way consistent with the experimental group, by the same criteria (presented in Table 2).

Based on Table 2 the schools from which the experimental and comparison groups were drawn could be characterized as high schools that are academic in nature (as opposed to rural or vocational schools). In general, such schools are characterized by relatively high inclination to the sciences. All the chemistry teachers of the experimental and comparison classes had at least 6 years of experience in teaching chemistry and were interested in improving their teaching methods and varying their instruction for the purpose of improving their teaching of chemistry. In addition, all the teachers (both in the experimental and comparison

Table 1
Comparison between static models in textbooks and visualized models in the Web-based activities

	Models in Books	Models in Web-Based Activities
1	One or two models	Variety of models (four models at least)
2	Static models	Static and dynamic models
3	No interactive models	Interactive models
4	Usually 2-D representation of models	2-D and 3-D representation of models

Table 2
Description of the research population

Criterion	Experimental Group	Comparison Group
Number of schools	7	5
Number of classrooms	7	5
Average number of students in a classroom	24	20
Total number of students	161	93
Socioeconomic status	Average	Average
Average teachers' seniority in teaching	19	22

groups) participated in in-service professional development training prior to this study, regarding teaching 10th grade chemistry. The training includes content and pedagogy regarding teaching the concept of *chemical bonding*. In order to validate the similarity of the two groups, we administered to all the students that participated in this study an achievement pre-test that examined their knowledge (see the *Achievement Pre-Test* results). This enabled us to characterize the experimental and comparison groups regarding their similarities or differences.

Teaching the Concept of Chemical Bonding

The educational system that prevails in Israel dictates the curriculum and all students study the same syllabus. Thus, all students study the concept of *chemical bonding* for the first time in 10th grade. Both the experimental and the comparison groups participating in the study learned the basic *chemical bonding* topics, as required in the school curriculum, based on the Bohr model of atom, in which the chemical bonds are determined by the valence electrons in the "outermost" shell of an atom. Based on the curriculum, the students learned about the structure of metals, ionic and molecular substances at the particle level, and types of chemical bonds: metallic, ionic, and covalent bonds, the properties of substances, and the connection between the structure of a substance and its properties. The students study 2-D and 3-D representations of models as well as ball-and-stick and framework models. More specifically, they build models of molecules, draw models of different substances, use movies to demonstrate the different structures of different substances, and perform laboratory experiments. Students were also given exercises in the classroom and for homework. All teachers taught using the same textbooks and allocated 40 lessons to teaching *chemical bonding*.

Integrating the Web-Based Activities into the Learning Process

Teachers in the experimental group were given an intensive 3-day in-service induction course in which the rationale for setting up the website was presented, as well as its structure and content. Web-based activities dealing with *chemical bonding* were emphasized as well as pedagogical methods of integrating the activities into the regular chemistry lessons. The students in the experimental group were engaged in four web-based activities dealing with *chemical bonding*. Each of these activities was conducted immediately after instruction on a relevant topic in the classroom. Activities were conducted in the computer laboratory at the schools, and two lessons were devoted to each activity. The teachers generally began the lesson with a brief introduction (5–10 minutes) on how to conduct the activity, and they handed out instruction sheets. Most of the lesson was devoted to engaging in the activity. The students worked in groups of two and three, with the teacher moving among them, guiding and providing support when needed.

Note that the two groups (experimental and comparison) followed the same basic syllabus and used the same textbook, and did the same activities. Also, the same length of time, namely, 40 class periods were devoted to teaching the concept of *chemical bonding*. The only difference between the two groups was that the experimental group of students was exposed to the website and performed the above-mentioned four activities.

Research Methods and Tools

This study incorporated both quantitative and qualitative research. The quantitative research consisted of achievement questionnaires administered to both the experimental and comparison groups. The qualitative research included gathering data from small groups of students and teachers, with the goal in mind of helping in the interpretation of the quantitative results. The diverse range of data collected enabled triangulation of the results obtained from the conversations between the students during the activities, the achievement tests, and the interviews with the students and teachers.

The Quantitative Dimension of the Research

Achievement Pre-Test. The purpose of the pre-test was to compare the two groups' (experimental and comparison) level of understanding of chemistry at the beginning of 10th grade. The aim was to assess their initial level of knowledge in chemistry in general and in understanding of basic concepts in chemistry taught in middle school in particular. The test consisted of ten multiple-choice-type questions on the following topics: basic terminology in chemistry (the chemistry language), the states of matter, and the structure of the atom and its elementary particles. However, this test did not include questions about the *chemical bonding* topic since the students did not study this subject in middle school. This fact was strengthened by teachers of both groups, who claimed that *chemical bonding* topics were studied for the first time during the 10th grade. The test however consisted of chemical content which provides the basis for understanding the concept of *chemical bonding*.

The test was developed and validated by four chemistry teachers who had at least 10 years experience in teaching 10th grade chemistry, and it has a reliability of Cronbach's α internal consistency of 0.65. It was administered to both the experimental and the comparison groups at the beginning of the school year.

Achievement Post-Test. The purpose of the post-test was to determine the students' understanding of the concept of *chemical bonding* taught in 10th grade chemistry. Students have generally been asked questions at a basic level that requires rote learning of material rather than an in-depth understanding of the structure of matter. Hence, students often provide correct answers without having a deep and thorough understanding of the concept of *chemical bonding*. The post-test was designed to examine in depth how the different types of chemical bonds are understood, and also how the structure of matter at the particle level is understood.

The test included questions that examined students' understanding of atomic structures and the structures of ionic, metals, and molecular substances as well as the differences between them, and students' understanding of the nature of chemical bonds. It also examined students' comprehension of the connection between the structure of a substance and its properties and their acquaintance with the use of the substances in everyday life (relevance).

The achievement post-test was validated by five experts (teachers and science educators) who were asked to judge each question by the following criteria:

- The question is compatible to the *chemical bonding* topics studied according to the syllabus.
- The question is well phrased and clear.
- The level of the question (easy, middling, difficult).
- The question was classified according to the Bloom taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956).
- The question examines the comprehension of the structure of matter (metal, ionic, or molecular) and/or the differences between them.
- The question examines students' understanding of the chemical bond (metal, ionic, or covalent bond) and/or the differences between them.

The experts responded that the questions in the post-test are compatible to the *chemical bonding* topics studied according to the syllabus in 10th grade. Based on Bloom's taxonomy, most of the questions examined a deep understanding of the concept of *chemical bonding* and only a few questions examined knowledge and applications. Some of the questions were then rephrased, based on the experts' comments and were included in a pilot test (administered a year prior to the main namely current year). At the end of the process, the post-test included four open-ended questions and 17 closed-ended (multiple-choice-type questions with arguments). The test was found to be reliable (Cronbach $\alpha = 0.91$).

In addition, 11 teachers were asked to evaluate in advance the performance level of the students needed to answer each question in the achievement post-test as follows: 1 = low performance level, 2 = medium performance level, 3 = good performance level, 4 = very good performance level. Based on this evaluation, the expected average performance level was between 2.5 and 3, which means that teachers think that students will be able to cope properly with the achievement post-test. This tool enables us to determine whether the structure and contents of the achievement post-test are adequate for 10th grade students according to the syllabus and the *chemical bonding* topics, and also according to students' ability to answer the questions.

To examine and score the questions in an objective manner, we developed rubrics. For example, for question 1a (see Quantitative Results Section), the correct answer is: the illustration depicts the metal copper as composed of positive copper ions (or positive atomic cores of metal), and a ''sea of electrons'' from the outermost shell of electrons. Students, who provided the correct answer as written above, received three points. If the student describes the existence of positive ions of metals or electrons, he receives one and half points, if the student does not refer to both particles, he receives zero points. In such a way, the rubrics were written for all the open-ended questions.

The test was administered to the experimental and comparison groups upon their finishing their study of the concept of *chemical bonding*. The tests were anonymously reviewed by the class teachers using the rubrics. Furthermore, all the achievement post-tests were examined by one of the researchers of this study, to verify that the assessment was conducted by the teachers according to this rubric. In the majority of the classes there was almost full agreement between the various ratings. In few of the cases (about 5%) in which agreement was not reached the test was rechecked.

The Qualitative Dimension of the Study

Since the main goal of this study was to explore the contribution of a web-based learning environment to the learning process and to ascertain students' understanding of the concept of *chemical bonding*, the researchers were interested in studying how teachers and learners used web-based activities, in science lessons. Hence, the observations and also students' interviews took place in the experimental classrooms only, because the experimental group was the only one that conducted the web-based activities.

Experimental and comparison teachers were interviewed to determine their instructional strategies, the curriculum they taught in 10th grade, and to ensure that they taught all the relevant topics regarding the *chemical bonding* topic.

Observations in the Experimental Group Classes. The purpose of the observations in the experimental group classes was to examine in depth how the web-based activities were integrated into the teaching of the topic *chemical bonds* and how they helped the learning process and improved students' understanding of the subject matter. The four experimental group classes were observed regarding each of the four activities (for a total of 16 observations constituting 32 lessons). Two (generally) constant groups of students in each of the four classes were taped while conducting the web-based activities (eight groups in all).

The conversations of six groups of students were transcribed (two groups from three experimental group classes) in all the activities they were engaged in, and several segments of conversation discussing the structure of matter were subjected to qualitative analysis. Each segment of conversation lasted 4–6 minutes. We chose to analyze the discussions and deliberations held in groups of students who were verbal and outspoken. Thus, we could audio record them.

The analysis consisted of three stages:

Stage A: Characterizing the students' actions in the group: reading, discussing, arguing, writing, thinking, and formulating an answer.

Stage B: Analyzing the essence of the action: addressing the instructions and their implementation, and focusing on how the activity was conducted.

Stage C: Scrutinizing the learning process: consolidating and increasing the depth of knowledge, building on top of existing knowledge, and understanding the material. This stage also examined the application of learning theories: active learning, cooperative learning, and a constructivist approach to learning.

Interviews

In-depth interviews were chosen for the present study in which the interviewer did not limit the interviewees by guiding their answers but instead enabled them to express themselves freely. In such an interview, the interviewers focus on several topics to help the interviewees relate their story about the investigated phenomena in their own language and in a narrative way (Shkedi, 2003, p. 70). In depth interviews provide, the interviewees with opportunities to present freely their attitudes and their opinions based on their experience from their respective chemistry classrooms.

Interviews with the Experimental Group Students and Teachers. Four teachers from the experimental group and 3 students from each of the four experimental group classes observed (12 students in all) were interviewed separately. Each student interview lasted 30–40 minutes and each teacher was interviewed for about an hour. The issues discussed in the interviews were as follows: chemistry studies in 10th grade in general, the affective and cognitive contribution of the website activities to the students and to the learning process, and also the contribution of the activities to the understanding of the concept of *chemical bonding*.

Interviews with the Comparison Group Teachers. The teachers in the comparison group were interviewed for about an hour regarding their teaching of chemistry in general and about teaching the *chemical bonding* topic in particular. They were asked to report about methods of instruction, demonstration tools, teaching aids, projects done by students in the classroom and at home, and the time allocated for instruction on *chemical bonding*. The purpose of the interviews was to verify that the students in the comparison group had indeed learned about *chemical bonding* effectively.

The interviews were transcribed and analyzed using a qualitative-constructivist analysis by Shkedi (2003), divided into four stages:

Stage A: preliminary analysis—categorization.

(1) Breakdown of the information into small, meaningful fragments, and assignment of a title to each segment that reflects its contents.
(2) Classifying the data segments according to subject, combining fragments of information according to subject (in a different and new order)—and assigning a name to categories.

Stage B: Mapping analysis: identifying relationships between categories, combining several categories under one umbrella category so that each umbrella category contains sub-categories.

Stage C: Focused analysis: focusing in on several items of information to provide a coherent explanation around one or more core categories. Each core category has sub-categories. At this stage, the focus is on the categories relevant to the questions investigated by the study.

Stage D: Theoretical analysis: constructing theories and conceptual–theoretical explanations about the phenomenon investigated, that is, translating a core category and the sub-categories from everyday concepts into theoretical notions. This stage was taken from the "grounded theory" approach to analysis (Strauss & Corbin, 1994).

Data Analysis and Results

Quantitative Results

The Achievement Pre-Test Questionnaire. The purpose of the pre-test was to examine whether initial differences existed between the experimental and comparison groups. To this end, a statistical *t*-test was performed on the pre-test. It was found that mean score and standard deviation of the comparison ($N = 93$) group were 72.2 (19.0) and for the experimental group ($N = 161$) 73.3 (19.5) $t = 0.45$, p-not significant. Thus, no initial significant differences exist between the groups.

To strengthen (and validate) the results regarding the similarity between the two groups a Chi-square test between the distributions of the scores of both groups was performed: $\chi^2_8 = 5.61$ (p = not significant). These results strengthened the assumption that the groups were similar in terms of initial achievement and the initial level of chemistry knowledge. Moreover, it strengthens the similarity in the characteristics of the groups as determined according to criteria presented in Table 2.

The Achievement Post-Test Questionnaire. Based on the similarity of the groups, which had the same initial baseline, a statistical *t*-test was performed on the whole achievement post-test, aimed at determining whether differences existed between the experimental and comparison groups in student achievements regarding the concept of *chemical bonding*. It was found that the mean score of the experimental group ($N = 145$) and the comparison group ($N = 88$) was 76.1 (17.0) and 63.4 (16.2) respectively, $t = 5.7, p \leq 0.001$.

As shown above, the experimental group's mean score regarding the concept of *chemical bonding* was significantly higher than that of the comparison group.

The test included questions on various topics. Since this article addresses *chemical bonding* only, Multivariate Analysis of Variance (MANOVA) was conducted to determine whether differences generally exist between the two groups on the sub-tests for three topics that were included in the post-test, namely, metals, ionic compounds, and molecular compounds. The results for the MANOVA are Wilk's $\lambda = 0.88$, $F_{(3,229)} = 10.8$ ($p < 0.0001$), which indicate that overall, a highly significant difference exists between the achievements of the two groups in the sub-tests analyzed. Analysis of Variance (ANOVA) tests were conducted to determine the differences between the groups in each of the sub-tests examined. The results are presented in Table 3 and in Figure 1.

As shown in Table 3 and Figure 1, the mean scores of the experimental group on the sub-topics examined in the test were significantly higher than those of the comparison group, that is, the achievement level of the experimental group students was higher in all the sub-topics of *chemical bonding* examined.

Close examination of the test reveals that most of the questions on which a statistically significant difference were found between the experimental and comparison groups dealt with understanding the structure of matter (metallic, ionic, and molecular). The following is an example of a question in the achievement test that dealt with the structure of metal, question 1a (open-ended-type question).

(1) Look at the illustration presented (Figure 2) and answer the following:

a. The illustration depicts a model of a metal lattice. Explain the structure of the metal lattice according to the given model.

About 75% of the students in the experimental group answered this question correctly, whereas only 55% in the comparison group answered it correctly. The following are typical examples of correct answers of students:

The illustration depicts the metal copper, composed of positive copper ions and a "sea of electrons" A very strong attraction exists between the positive metal ions and the electrons; hence, the structure is orderly and solid.

The metal lattice presented in the illustration is a copper lattice. It consists of positive atomic cores of the metal (nucleus + internal energy levels) surrounded by a sea of electrons (the outermost shell of electrons).

Typical examples of incorrect (or partially correct) answers of students:

Metal lattice structure: According to the model, negative ions are attracted to each positive Cu^{+2} ion. There is attraction between the positive and the negative.

Table 3
ANOVA results for student achievement post-test

Sub-Tests	Experimental Group, $N = 145$; Mean (SD)	Comparison Group, $N = 88$; Mean (SD)	*F*-Value and Significance Level
Metals	74.33 (21.28)	61.01 (20.83)	21.79***
Ionic compounds	76.70 (16.88)	64.49 (17.69)	27.64***
Molecular compounds	71.90 (19.51)	58.43 (18.97)	26.66***

***$p \leq 0.001$.

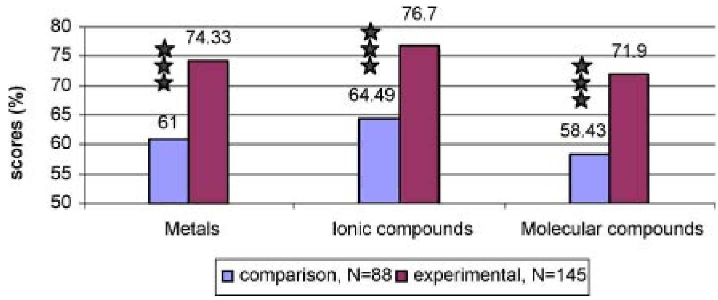


Figure 1. The mean scores in the sub-tests of the achievement post-test. ***$p \leq 0.001$.

It is a metal substance in a solid state containing negative ions in motion around the positive ones. It has a high melting point and is malleable.

Based on these results, it is evident that most of the students in the experimental group correctly addressed the structure of the metal and its components in their answers. That is, the vast majority of the students in the experimental group grasped the concept of the structure of metals and the particles comprising it. On the other hand, a higher percentage of students in the comparison group confused electrons with negative ions and actually did not understand the structure of metals.

A similar analysis of additional questions dealing with ionic and molecular structure *of chemical compounds* revealed similar results, namely, that a higher percentage of students in the experimental group than in the comparison group understood the subject, specified correctly how the different particles and structure of the ionic and molecular compounds are composed, and distinguished between a single molecule and an agglomeration.

Qualitative Results

Analysis of the Classroom Conversations. After the students had finished learning all the relevant subject matter on metals, they became engaged in an activity called "Metals—Structure and Properties." One of the goals of the activity was to summarize and revise the material learned in the classroom and to demonstrate the metal model, the metal lattice, and metal bonds using various visual computer-based models available on the Internet, in order to deepen and scaffold the students' understanding of the structure and *chemical bonding* in metals. The choice of segments of conversation for analysis was made following the results of the achievement test on *chemical bonding*, in which significant differences in the questions that tested students' understanding of the structure of matter were found. Consequently, the segments of conversation dealing with the structure of matter were selected for analysis, in order to examine closely and comprehensively the learning process taking place while the students were engaged in the activities.

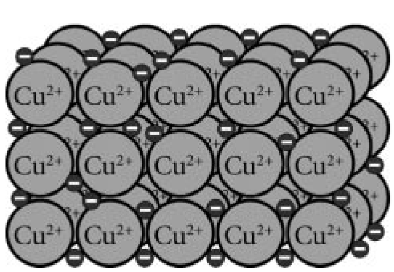


Figure 2. A model of a metal lattice.

Table 4 presents a segment of conversation and its related analysis conducted by a group of students during and following the above-mentioned activity.

The segment presented in the above table is a transcription of the discourse between two students while engaged in an activity dealing with several visual models describing the structure of metals. It is clear that the students are focused on carrying out the activity and the tasks required. They read, explain to each other, formulate an answer, and give each other feedback. During the activity, the students interact and cooperate in interpreting the visual models for the structure of metals. Note that an argument arose (subsequently, regarding the second model) about the identity of the ‘‘minuses’’ in a different visual model describing the structure of metals. The first student (Avi) argued that they are electrons, whereas the second (Tal) maintained that they are negative ions. The students worked together and discussed the questions on their own, but the moment a problem arose, they asked the teacher to clarify the issue.

The following is a conversation that was held between some students and their teacher:

> Teacher: (reading their answer): The circles are the ions with positive charges; around them are the minuses representing ions with negative charges. Is this what you think? What is the structure of a metal lattice?
> Avi (student): Metal lattice . . . it's written here (referring to the answer they wrote before) and here is the sea of electrons.
> Teacher: Ions that are positively charged; where are the negative ions?
> Avi: The electrons.
> Teacher: So what do you think: Are the ions electrons?
> Tal (student): No, these are not ions only electrons that a..a. . .a..aaa. . .!
> Teacher (summarizing): So what kind of particles do we have here?
> Tal: Yes, these are electrons.
> Avi (writes down): These are electrons that are moving.

With the aid of insightful questions from the teacher, the students realized that the ‘‘minuses’’ in the illustration are electrons, not negative ions. This is only one example that demonstrates how a conversation with teachers, combined with their experience with the activity on the website, helped them understand the idea of metals and their respective structure.

The students engaged in the activity only after they had learned the subject matter in the classroom. Nevertheless, they encountered difficulties in understanding the structure of metals, with some students confusing different particles. The complexity of the subject matter, the many types of particles involved, and the abstract nature of the subject matter meant that students, often the high achievers as well, encountered serious difficulties. Confusion over particles occurred in five groups (out of six) in three different classes that were engaged in the activity on metals, particularly in the initial stages. This generally indicates that the structure of metals was not properly understood in the framework of ‘‘regular’’ lessons in the experimental group class.

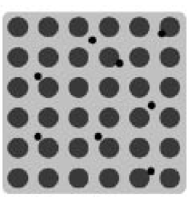
A similar analysis of segments of conversation taken from the activities of additional groups in other experimental group classes that engaged in activities dealing with particulate, ionic, and molecular structure revealed the same results.

The web-based activities induced students to become intensively involved in the learning process in which the students are active, while they interacted with their friends and discussed the questions to achieve meaningful learning by means of a constructivist approach to learning. Analysis of interviews below reinforced these results.

Analysis of Interviews

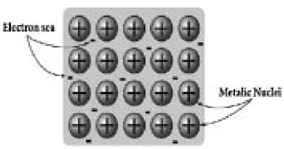
In-depth interviews were conducted as described above in which the teachers in both groups were asked to talk about teaching chemistry in general and teaching *chemical bonding* topics in particular, as well as methods of instruction, demonstration tools, teaching aids, and the way their students studied, especially the topic of *chemical bonding*. This kind of interview enables teachers to speak freely about their chemistry classes. For example, experimental teachers chose to speak about the way their students studied in the web-based learning environment, namely, student-centered approach. On the other hand, the comparison

Table 4
Two questions that dealt with models representing the structure of metals, a segment of a student's conversation, and an analysis of it

Questions from the website activity	Conversation	Activity	Analysis
1. *There is a list of websites specifying the structure of metals. Describe the structure of metals in your own words, and add an illustration.*	Avi: (reads) There is a list of websites specifying the structure of metals. Describe the structure of metals in your own words, and add an illustration.	Avi reads	1. The students relate to what is required of them in the activity and follow the instructions.
Three websites were listed for visual models of the structure of metals. One of the sites presents the following animation:  In the animation, one sees that the large spheres are stationary, and the small ones are in constant motion.	Tal: What's the question? What's the question?	Tal asks	2. The students focus on carrying out the activity.
	Avi: We have to describe in words what we see; we have to describe the structure of metals in words.	Avi explains the question.	
	Avi: (writes) Well, metal is arranged in a metal lattice in which the positive ions are arranged in rows, and the electrons are around them in a sea of electrons.	Avi phrases loudly and writes the answer.	3. The student explains the structure of metals, and in the process, connects the visual model in the activity to the theoretical model taught in the classroom.
	Avi: Yes... what do you think about my amazing formulation?	Avi requests feedback.	
	Tal: Nice. You have my approval.	Tal gives positive	

(*Continued*)

Table 4
(Continued)

2. Choose one of the illustrations and specify what each item in the illustration signifies.  Static model for the structure of metals (the large balls are red)	Avi: (reads) *Choose one of the illustrations and specify what each item in the illustration signifies.* Tal: How can you write it? Write please... the red balls that are denoted by + Avi: The red balls are positive ions with positive charge. Tal: These lines... the minuses between them... Avi: (writes): the minuses around them are electrons, is it correct? Tal: What? Show me, (reads) the minuses around them are electrons, correct. Avi: They have negative charge. Tal: Sure...no they are ions with negative charge. Avi: They are electrons... Tal: They are ions, ions.	feedback. Avi reads Tal thinks and tries to answer. Avi continues the answer. Tal continues the answer. Avi write down the answer and asks for feedback. Tal reads and gives feedback. Avi finishes the answer. Tal and Avi argue.	4. There is an interaction between the students. They cooperate and help each other to understand the model representing metals. 5. There is confusion about the kind of negative particles that compose the metal.

group teachers who did not implement web-based activities in their classes chose to discuss learning contents, instructional aids, and the instructional process that took place in their classes, namely, teacher-centered approach. In-depth interviews enabled teachers to relate their unique story, so we could recognize the differences between them. The differing results highlighted the differences between the web-based learning environment and the ‘‘regular’’ classroom learning environment, as can be seen, according to the analysis of the interviews afterwards.

Analysis of Interviews Conducted with Teachers and Students in the Experimental Group. Analysis of the interviews revealed three key factors that contributed to learning and understanding the concept of *chemical bonding*, as a result of integration of web-based activities. The three factors are (1) identifying students' difficulties regarding the concept of *chemical bonding*, (2) use of a constructivist approach to learning, and (3) use of computer-based visual models, which it is assumed contributes to greater understanding.

Identifying Students' Difficulties with the Concept of Chemical Bonding

All teachers interviewed indicated that the concept of *chemical bonding* are too abstract and that the students had difficulties in understanding them. The students confused particles of varied substances; therefore, most students could not understand the structure of matter and its particles in the theoretic studies that took place in class.

> Teacher (Shula): The students had difficulties in understanding the kind of lattice . . . then they confuse, for example, a metal lattice and ionic . . . they confuse particles.
>
> Teacher (Aviv): . . . for example, the particle nature of structure, when students have an abstract concept, a high percentage of students has difficulties in understanding the microscopic level.
>
> Teacher (Amit): You can see that although they (students) finished studying the relevant contents in class, while they did the web-based activities, I observed that they did not understand well the contents taught in class.

A Constructivist Approach to Learning

Constructing Knowledge. The activities promote a constructivist approach to learning with the student at the center of the learning process; the student builds up knowledge, and constructs it on the basis of previous knowledge. Guided web-based learning consolidates knowledge and leads to a more in-depth understanding of the subject matter; it differs from the "regular" method used in the classroom, which, for the most part, is based on rote learning. Here are some quotes from students and teachers that were interviewed:

> Student (Eli): It's a matter of adding one thing to another, and in the end, everything adds up. It is better understood when you have to formulate an answer rather than listening in the classroom. The activity contributed to a more in-depth understanding of things and that is a change in the way of learning. Here you feel that you understand the subject matter better and that you are not simply learning it by heart.
>
> Teacher (Mina): While engaging in the activity, they ask questions, and they need me . . . in the classroom I am the one who usually asks the questions; it is a major difference . . . for a student to ask a question, he needs to know; he needs to be in a different mode than in the classroom when I ask a question.

Active Learning. Almost all the teachers and students interviewed indicated that web-based activities facilitate student-centered active learning. In the opinion of the interviewees, this type of activity encourages students to focus on the learning process and thus, it is thought that this enhances their understanding. This type of learning differs from "regular" learning in the classroom, where students are generally passive. Some of their comments follow:

> Student (Mali): It causes you to be more active; it simply causes you go more deeply into the subject matter, makes you understand it better, because in a regular lesson you lose concentration.
>
> Student (Mira): Here, you have to be focused . . . In the classroom you are more passive, you take less action; here you have to have to apply your self more.
>
> Teacher (Shula): It's not like a lesson I teach in . . . here it is active learning, it certainly contributes to learning, it contributes to more in-depth learning . . . I felt that they understood more, that it was more consolidated.

Cooperative Learning. The teachers noted that conducting the web-based activities in small groups enabled the students to cooperate; they helped one another; there was learning interaction that one does not generally find in the "regular" classroom.

Teacher (Shula): There is teamwork, one knew more, another knew less . . . there was interaction between them and they could help each other. This does not exist in a regular lesson.

Teacher (Aviv): . . . and it is also necessary to divide up the tasks among the students when discussing various issues and questions. One thinks this, another thinks something different and they learn well from one another . . . Yes, I know of several groups in which they really explained to one another.

Teacher (Amit): They worked together, one told the other what to write, they thought together, observed together, deliberated together . . . they explained to one another.

Computer-Based Visual Models Contribute to Understanding

Visual Demonstration Tools to Enhance Understanding. Most of the students claimed that it was difficult to understand *chemical bonding* topics from the teacher's explanations in class. Students and teachers who were interviewed indicated that the animations and computer-based models contributed to visualizing the abstract concepts of *chemical bonding* taught in the classroom and helped students to "see" the structure of matter.

Student (Mali): The animations and models demonstrate the model to us. You really don't understand how the ions and electrons actually move, and what really happens, and then you see it in an animation. Then you understand it better.

Student (Eric): The models and animations are a visual way of demonstrating the subject matter, and it is better when you see it, because sometimes it is difficult to understand it only from the teacher's explanation.

Teacher (Aviv): When students see the micro and the structures in three dimensions and the electron cloud on the computer, they see that the models of molecular substances have volume, that there is motion . . . and how one atom is arranged opposite another atom, and they see the connection between them. This expands their understanding and gives them in-depth understanding. I think that this contributes a great deal to the learning of concepts in *chemical bonding*.

Using Dynamic Models Versus Static Models. The students said that they had difficulty in imagining the construction of matter, and they preferred the dynamic models in the web-based activities instead of the static models that teachers showed them in class.

Student (Amir): When the teacher explains something in the classroom, you don't have any way of imagining it, how it looks; even when the teacher draws a diagram on the board, it still is not like seeing it, as you do in an animation with color and 3-D demonstrations.

Teacher (Aviv): The animations are varied and diverse. What I can do is draw something static on the board, but the students can't see the particle in motion, which is the most important thing.

The Connection between the Macroscopic and Microscopic Levels. Many students found it difficult to make the connection between the macroscopic and microscopic levels; the visual models on web-based activities help them in this process.

Student (Mali): When I saw the animations I made the connection, the connection between the structure itself and what happens there inside the structure.

Teacher (Mina): The animations are important because they help students make the connection between the micro and the macro, which is one of the most difficult things to do. The focus is on the models and on the micro, as opposed to the macro so that more students are able to understand.

Teacher (Aviv): It is important that the student will understand it at the micro level; with an animation, the student sees what is happening inside the substance; that is really important.

Analysis of the Interviews Held with the Teachers in the Comparison Group. Analysis of the interviews with teachers in the comparison group revealed that the instruction consisted of three key components: content, instructional tools, and doing exercises on the subject matter taught. The teachers in the comparison group talked about their methods of instruction and how they applied them:

Contents of the learning:

Teacher (Hilla): I taught the model of metals, the chemical bond between positive ions and electrons, and the structure of metals, which is a giant and infinite structure . . . I emphasized the difference between the structures of metal and ionic substances, which have giant structures, on the one hand, and a molecular structure, which is a small structure . . . I taught the ionic bond, covalent bond, and polar covalent bond. I teach in a sequential, structured, and logical manner.

Instructional aids for demonstration purposes:

Teacher (Tally): I show them models that appear in textbooks, which are two- and three-dimensional, and show them the movie "The Architecture of a Molecule." I use lots of models; they build molecules. I draw models on the board and they also draw models. I incorporate a lot of models, because they aid in understanding the material.

Exercises on the subject matter:

Teacher (Tally): A lot of exercises in the classroom, a lot of exercises to identify substances by means of their properties, like in the national matriculation exams.

From the interviews with teachers in the comparison group, it is clear that they taught all the content required in a highly structured and organized manner. They also used various static models (such as graphic depictions and ball-and-stick models), and gave the students exercises on the entire subject matter. All these are in alignment with the "traditional" format of instruction, in which basically the teacher teaches the subject matter, is responsible for the instruction process (teacher's centered learning), and does not refer to the students' learning process.

Discussion

In this study we studied the effectiveness of web-based chemistry by using quantitative and qualitative tools. The quantitative research compared the achievements of the experimental and the comparison groups and examined the differences between them, whereas the qualitative assessment tools were used to investigate the learning process that occurs during the web-based learning. This set of tools was needed to obtain a broad and clear picture of the process and the phenomena investigated in this study. The tools also enabled us to examine more thoroughly the contribution of the web-based activities regarding the teaching and learning of the topics *chemical bonding* and the structure of matter.

The question that was posed was how did the web-based activities contribute to students' better understanding the structure of matter and the concept of *chemical bonding*?

The answer to this question was obtained from a thorough investigation and triangulation of the data from the qualitative and quantitative findings of the study. It was found that the web-based activities, that contained various visual models, helped most of the students by providing them with a visualized demonstration of the structure of matter. Presenting one or two models in a textbook or on the blackboard, as is done in traditional classroom teaching, limits the comprehension of the models and the understanding of structure of matter. For example, usually there is no reference to the model's limitations. Thus, the student might draw an incorrect or wrong model for the structure of matter (Barnea & Dori, 2000; Justi & Gilbert, 2002). In contrast, the web-based activities contain a variety of visualized models, each of which represents one aspect of the structure of matter; therefore, many models can provide students with an extensive picture of the structure of matter. In addition, the students refer to the model's limitations. In this way, the students realize that there is no model that represents the correct structure, but altogether the models could enhance the comprehension of the structure of matter. Furthermore, static models cannot describe dynamic phenomena. For example the static models of metals in which all particles are firmly fixed are limited in their potential to scaffold students understanding regarding motion of electrons and its resulting electrical conductivity. This is not the case regarding dynamic models as was used in our study. The students in the experimental groups were exposed through the web activities to several different computerized models (static and dynamic, two, and three dimensional). These were in addition to the models presented in class. This approach helped them to better understand the concept of *chemical bonding*, as was evident in the achievement post-test that examined the comprehension of the structure of matter and its particles. Those results are in alignment with interviews that were analyzed in which teachers and students in the experimental group declared that the visualization tools helped students to better understand the concept of *chemical bonding*. The computerized models help students make an effective connection between the macroscopic level and the microscopic level, something many students find difficult to do (Johnstone, 1991; Robinson, 2003; Tsaparlis, 1997). In addition, the visual tools contributed significantly to students' understanding and their internalization of the abstract aspects of *chemical bonding*, the theory of which they had learned in the classroom. Several studies that investigated the integration of computer-based models in web-based learning support similar results, namely, that use of computer simulations, animations, and visual tools contributes to greater achievements and improved understanding of concepts among students (Ardac & Akaygun, 2005; Barnea & Dori, 2000; Carpi, 2001; Marbach-Ad et al., 2008).

We found that while the students were engaged in the web-based activity presented in the educational website, they were motivated to focus on the activities and the learning process. Such activities effectively promote a constructivist approach to learning, in which the student is at the center of learning and is responsible for the learning process, by building up knowledge, and constructing new knowledge on top of previous knowledge, and relating new knowledge to the subject matter learned in the classroom. Own (2006) For example claims that "...the network and multimedia are useful tools for developing the learning environment with a constructivism learning approach. Well-designed, web-based instruction will become a crucial part of implementing constructivist style instruction." The importance and benefits of active learning are well-documented in the literature (Bonwell & Eison, 1991; Felder & Brent, 2003; Lagowski, 1998; Moore, 1989). Lagowski (1998), for example, noted that the integration of technology into learning promotes active learning and helps improve academic performance and students' attitudes as well as it reinforces positive interaction between teachers and students. Digital technology shifts the focus from traditional instruction, based on a lecture format in which students are, for the most part, passive, to a learning format in which the student becomes more active (Moore, 1989). Based on the current study engaging in web-based activities, shifted responsibility for the learning process from the teachers to the students. For example, the students turn to the teacher with questions in order to grasp and understand the subject matter, and not vice versa. One can argue that good teachers would be able to challenge their students and cause them to ask questions without the web-based activities. However, this is much more feasible in our web-based learning environment than in a more "traditional" classroom learning environment, where the teacher is more active and is responsible for both the teaching and learning processes. Cooperative learning also occurred, as reflected in the interactions between the students within small group discussions. The students clarified and discussed the questions while performing the web-based activities; hence they gave the issues deep thought and consideration. This discourse has potential to encourage the development and practice of metacognitive activity that again might induce the enhancement of more meaningful learning. The web-based activities promote high-level thinking in which the students associate the theory of *chemical bonding* learned in the classroom with the visual models they observe in the web-based activities. This is in alignment with the study conducted by Krystyniak and Heikkinen (2007) that found that the verbal interactions indicate that students processed what they had observed in laboratory activities and linked it to the previously learned chemistry content. The web-based activities afforded the students the opportunity to appreciate the essence of the metal, ionic, and molecular structures, and to learn more in-depth about them in order to gain a better understanding and to consolidate their knowledge. In the present study we found that web-based learning was a significant addition to the teacher's explanations in class, since it served as scaffolding and supported the students' learning process, and indeed promoted cooperative and active learning within a community of learners using a constructivist approach.

Limitations of the Study

The current study had some limitations. First, the sampling of the population; regarding the experimental group, we approached only those schools that possessed the appropriate technology and that consisted of teachers who were willing to implement a web-based learning environment. Second, this study aimed at exploring the educational effectiveness of the web-based learning environment. Thus, most of the qualitative part of the research focused on the experimental group (in which the web-based activities were implemented), whereas the quantitative part of the research was performed equally in both groups. The comparison group underwent neither observations nor students' interviews. We are aware of the drawback of this approach, but we believe that it did not interfere with the main goal of this study, namely, to examine the contribution of web-based activities to the learning process. Third, based on our findings, it is clear that the web-based activities improved students' understanding of the concept of *chemical bonding*. However, we have no clear evidence whether this improvement resulted from the animations or from the pedagogy chosen to implement the web-based environment. More research is needed in which better control will be provided regarding these variables. Fourth, one should take into consideration that this study is typical of studies in which we compare the implementation by using experimental and comparison groups. Such studies have the potential to be exposed to what is fondly called the "Hawthorne effect." More research should be done in the comparison group classes as well as in the experimental group classes to validate the results that were obtained. Another limitation is the use of different achievement tests for the pre-test and post-test. The pre-test focused on topics that were already learned before, whereas the post-test dealt with new topics. We made this decision because the study was conducted in an authentic classroom situation in which the ability to interfere with the normal classroom activities was limited. In addition, using the same test as the pre- and post-test has the potential to frustrate the students since it meant introducing (in the pre phase) questions covering topics that were completely novel to them.

Conclusions and Implications

The main contribution of the current study is in the development and formulation of a pedagogical model for effective use of web-based learning in chemistry studies, by taking advantage of its educational and organizational benefits. Our pedagogical model suggests the following steps should be considered as part of the implementation process: (1) training teachers for effective use of a web-based learning environment as well as learning appropriate pedagogical methods of integrating the web-based activities into regular chemistry lessons, (2) before conducting the web-based activities teachers should be asked to teach in advance all the theoretical aspects that underline the topic and the chemical concepts that are relevant to the web-based activities, (3) the students are actively involved in the learning process, work in small cooperative groups in which they discuss the learning materials, ask questions, provide each other with feedback, explain their ideas to their peers, and answer the questions in their own words. Thus they construct their knowledge step by step constructively. (4) The teachers guide students, identify and recognize students' difficulties, and provide them with support whenever needed.

The use of a website as an instructional method is rather new. Therefore more intensive and comprehensive research is needed in order to explore and obtain insight regarding its pedagogical potential as compared to other teaching strategies and among different students' populations. More research is required to examine the effectiveness of the integration of web-based activities into the learning process and understanding of scientific concepts regarding students with different abilities and learning styles. In addition, it is recommended to research the implementation of this instructional tool with different teaching style. Since the learning activities consisted of few components (the web-based environment and the animations) more research should be conducted to investigate the question whether the web-based component or the animation make the difference regarding the students comprehension of scientific concepts in general and the *chemical bonding* concept and structure of matter in particular.

Finally, from the findings of this study, it can be concluded that structured web-based activities containing varied models for the structure of matter, which place students at the center of the learning process via cooperative learning in small groups, contributes significantly to students' understanding of the concept of *chemical bonding* and the structure of matter. It should be noted that providing teachers with professional development opportunities is a vital component in the implementation process for an effective integration of this innovative learning environment into the regular teaching and learning process.

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