J Sci Educ Technol (2013) 22:186–203
DOI 10.1007/s10956-012-9385-9

Effects of Jigsaw Cooperative Learning and Animation Techniques on Students' Understanding of Chemical Bonding and Their Conceptions of the Particulate Nature of Matter

Ataman Karacop · Kemal Doymus

Abstract The aim of this study was to determine the effect of jigsaw cooperative learning and computer animation techniques on academic achievements of first year university students attending classes in which the unit of chemical bonding is taught within the general chemistry course and these students' learning of the particulate nature of matter of this unit. The sample of this study consisted of 115 first-year science education students who attended the classes in which the unit of chemical bonding was taught in a university faculty of education during the 2009–2010 academic year. The data collection instruments used were the Test of Scientific Reasoning, the Purdue Spatial Visualization Test: Rotations, the Chemical Bonding Academic Achievement Test, and the Particulate Nature of Matter Test in Chemical Bonding (CbPNMT). The study was carried out in three different groups. One of the groups was randomly assigned to the jigsaw group, the second was assigned to the animation group (AG), and the third was assigned to the control group, in which the traditional teaching method was applied. The data obtained with the instruments were evaluated using descriptive statistics, one–way ANOVA, and MANCOVA. The results indicate that the teaching of chemical bonding via the animation and jigsaw techniques was more effective than the traditional teaching method in increasing academic achievement. In addition, according to findings from the CbPNMT, the students from the AG were more successful in terms of correct understanding of the particulate nature of matter.

Keywords Animation technique · Jigsaw technique · Chemical bonding · Spatial visualization

Introduction

Chemical bonding is one of the most important topics in undergraduate chemistry, and the difficulties students encounter in understanding the concept have been the subject of a great deal of research (Acar and Tarhan 2008; Doymus 2008; Coll and Treagust 2003; Frailich et al. 2009; Othman et al. 2008; Özmen et al. 2009). According to the literature, the abstract concept of chemical bonding is considered by teachers, students, and chemical educators to be very difficult and complicated (Frailich et al. 2009; Özmen et al. 2009). More specifically, atomic structure, the particulate nature of matter, the molecule, and the chemical bond are considered abstract concepts. It is also a topic that students commonly find problematic and they develop a wide range of alternative conceptions (Doymus 2008; Özmen 2008). The concepts of electron, ionization energy, electronegativity, bonding, geometry, molecular structure, and stability are central to much of chemistry, from reactivity in organic chemistry to spectroscopy in analytical chemistry (Frailich et al. 2009; Othman et al. 2008). Students' misconceptions regarding these concepts are based on the fact that they live and operate within the macroscopic world of matter and do not easily follow shifts between macroscopic and sub-macroscopic levels (Harrison and Treagust 2000).

Some chemical educators have stressed ways to make the learning of chemical concepts more explicit through the

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use of simple illustrations. One such approach to learning involves the teaching of the atomic, molecular, and ionic interactions responsible for observed chemical phenomena (Bunce and Gabel 2002; Johnstone 1991). This interaction is referred to as the particulate nature of matter. Numerous studies have documented the difficulties that middle, high school, and college students have in understanding of the particle nature of matter (Doymus et al. 2009; Merritt et al. 2007; Othman et al. 2008; Yezierski and Birk 2006). One of the reasons for the difficulties that students experience in understanding the nature of matter is related to the multiple levels of representation that are used in chemistry instruction to describe and explain chemical phenomena (Harrison and Treagust 2000; Othman et al. 2008). The acquisition of knowledge by students without a clear understanding may be attributed to the confusion caused in having to deal simultaneously with the macroscopic, submicroscopic, and symbolic worlds of chemistry. Students are often unable to see the linkages between the three levels of representation although they may know the chemistry at the three levels (Merritt et al. 2007).

Another and the most important reason of students' difficulties is the ineffectiveness of traditional teaching methods. A majority of teachers use teacher-centered strategies to teach chemistry (Yip 2001). These traditional teaching strategies are ineffective to help students with a complete understanding of the abstract concepts to build correct conceptions, to alleviate alternative conceptions, and to promote conceptual change. Because of this, teachers may need to consider alternative teaching approaches—particularly for difficult and abstract science concepts. Some authors suggest that this might be achieved by using more learner-centered approaches (Acar and Tarhan 2008; Doymus 2008; Frailich et al. 2009; Özmen 2008; Özmen et al. 2009).

Student-centered teaching approaches include cooperative learning, group discussions, hands-on activities, concept mapping, conceptual change, problem solving, inquiry-oriented approaches, experiential learning, writing tasks, speaking activities, class discussions, case-study methods, simulations, role-playing, peer teaching, fieldwork, independent study, library assignments, computer-aided instruction, and homework (Chang and Tsai 2005; Larsson 2009).

Among these teaching approaches, animation and jigsaw cooperative learning have attracted the attention of teachers, school managers, and educational researchers (Doymus 2008; Doymus et al. 2010; Bratt 2008; Chang et al. 2010; Frailich et al. 2009; Kelly and Jones 2007; Kim et al. 2007; Özmen et al. 2009; Ploetzner et al. 2009). In the present study, the jigsaw cooperative learning and computer animation instruction were selected to compare their effectiveness on students' achievements in chemical bonding concepts and students' understanding of chemical bonding in the particulate nature of matter.

Theoretical Background

Cooperative learning is an instructional technique in which students work together in small structured groups in order to accomplish shared goals (Doymus 2008; Hennessy and Evans 2006; Johnson et al. 2007; O'Leary and Griggs 2010). Through a cooperative emphasis, the 'whole' student can be engaged in thinking about, learning about, and enjoying movement with their peers (Lafont et al. 2007; O'Leary and Griggs 2010). Research studies have clearly indicated the effectiveness of cooperative learning methods over either competitive or individual learning methods in the development of higher-order thinking skills as well as the achievement of greater learning outcomes (Abdullah and Shariff 2008; Souvignier and Kronenberger 2007; Stockdale and Williams 2004). Working in cooperative groups may provide several gains for students. Learning in cooperative groups may improve students' social competence, foremost their ability to collaborate with peers, and they may improve academic achievement among students (Bratt 2008; Lafont et al. 2007; Thurston et al. 2010).

The jigsaw learning technique is a structured, cooperative strategy that avoids many of the problems of other forms of learning in a group (Doymus et al. 2010). It was first developed and implemented by Aronson et al. (1978). The jigsaw method provides a cooperative learning environment which fosters learner activity, joint acquisition of content and mutual explaining. In implementation the jigsaw learning method has four stages. In stage one (introduction) the class is split into heterogeneous 'home' groups of between three and seven students. The teacher gives a short introduction of the subject matter and explains how it will be divided into subtopics. The rationale for using the jigsaw approach is also explained to the group. Stage two (focused exploration) each member of a home group chooses one particular subtopic. Now those students who have chosen the same subtopic meet in 'jigsaw groups' in order to study the material and prepare to teach it to their home groups. Stage three (reporting and reshaping) involves students returning to their home groups and reporting their findings and beginning to reshape their understanding of the topic. Stage four (integration and evaluation) consists of students putting their learning together to produce the completed piece of work. Stages three and four provide students with the opportunity to teach their newly acquired knowledge/skills to the members of their home group and learn the material taught by other members (Aronson et al. 1978; Doymus

2008; Hanze and Berger 2007; Hines 2008; Hedeen 2003; O'Leary and Griggs 2010; Souvignier and Kronenberger 2007; Zakaria and Iksan 2007).

In recent years, computer animations, along with cooperative learning methods, have played an important role in education. A computer-generated animation is a series of still computer-generated pictures that are presented in succession to create the illusion of motion, much like a picture flip-book (Burke et al. 1998). Animations differ from still pictures in that they offer two unique attributes that still pictures do not—trajectory and motion (Adadan et al. 2009; Doymus et al. 2010; Chang et al. 2010; Frailich et al. 2009; Ploetzner et al. 2009; Venkataraman 2009). The instructional effectiveness of computer animations may be explained using Paivio's dual-coding theory, which assumes that learners store information received in their working memory as either verbal or visual (pictorial) mental representations (Ardac and Akaygun 2004; Kelly and Jones 2007; Moreno and Valdez 2005; Sanger and Greenbowe 2000).

The use of visualization is important for teaching chemistry concepts. Visualization tools such as animations can be used to give an accurate and rich picture of the dynamic nature of molecules and molecular interaction, which are often very hard to grasp from text-based presentations of information (Rotbain et al. 2008). An essential requirement for learning chemistry is the ability to form mental models of processes at the molecular scale (Chittleborough and Treagust 2007; Russell and Kozma 2005). An approach that is increasingly being used to help students' developmental models is computer visualizations of molecular systems and processes (Gilbert 2005; Tasker and Dalton 2006; Venkataraman 2009).

Studies have suggested that students who receive instruction including computer animations or visualizations of chemical processes at the molecular level are better able to answer conceptual questions about particulate phenomena (Appling and Peake 2004; Ardac and Akaygun 2004; Kelly and Jones 2007; Su 2008; Williamson and Abraham 1995). On the other hand, there are some potential disadvantages of animated graphics over static ones. Because animations change over time, they cannot be inspected and re-inspected the way static diagrams can. The information in animations may be fleeting and hard to process (Tversky et al. 2002). Furthermore, studies have indicated that animations alone might not be sufficient to improve student understanding (Hubscher-Younger and Narayanan 2003) and different instructional methods employing animations to promote understanding have been considered (Chang et al. 2010; Schank and Kozma 2002; Vermaat et al. 2003).

Research Goal and Questions

The aim of the present study was to determine the effect of jigsaw cooperative learning and computer animation techniques on academic achievements of first year university students attending the classes in which the unit of chemical bonding was taught within the general chemistry course and these students' conceptions of the particulate nature of matter. The research questions of the present study are:

1. Is there a significant difference between treatment groups in terms of academic achievement, scientific reasoning ability and spatial visualization ability?
2. Does instruction using traditional teaching, jigsaw cooperative learning and computer animation create differences in students' achievements in terms of chemical bonding concepts?
3. Does instruction using traditional teaching, jigsaw cooperative learning and computer animation create differences in students' understanding of chemical bonding in the particulate nature of matter?
4. What significant qualitative differences exist between student descriptions of the chemical bonding in the particulate nature of matter?

Methodology

In analyzing the effects of teaching materials or teaching methods in different schools and classrooms, it is more convenient to use the quasi-experimental research design. A quasi-experimental design in which participants are not randomly assigned to the groups, instead, there are naturally occurring groups or groups to which participants are assigned for reasons other than randomizing the sample was used in this study. The study utilized "a pre-test/post-test non-equivalent comparison group design" (Creswell 2003; McMillan and Schumacher 2006) and one control group (CG) and two experimental group (AG and JG) were selected, and each treatment randomly assigned.

Sample

This study included 115 first-year undergraduate students from three classes of a general chemistry course taught by the researcher (first author) in a faculty of education in a university in the 2009–2010 academic year. One of the classes ($n = 36$) was defined as the jigsaw group (JG), in which cooperative learning (subjects jigsaw technique) was applied; the second ($n = 39$) was defined as the animation group (AG), in which the computer animation technique was applied; and the third (n = 40) was the control group (CG), in which traditional teaching was applied. Pre-service science teachers are admitted to this department only after they have successfully passed a university entrance exam. In addition, the students that came to the department where this research was conducted had been taught the same curriculum in high school. The educational system that prevails in Turkey dictates the curriculum and all students study the same syllabus. Thus, all students study the concept of chemical bonding for the first time in the 8th grade of primary school; then they develop it in the 9th and 10th grades in high school. Based on the curriculum, the students learned about the structure of metals, ionic and molecular substances at the particle level, 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.

Instruments

To verify the effects of animation and jigsaw techniques on the learning of science concepts, each group of students was given the pre-test at the beginning and the post-tests at the end of the study. Four instruments, the Test of Scientific Reasoning (TOSR), published previously (Yezierski 2003); the Purdue Spatial Visualization of Rotations Test (PSVT:R), also published previously (Bodner and Guay 1997); the Chemical Bonding Academic Achievement Test (CbAAT), and the Particulate Nature of Matter Test in Chemical Bonding (CbPNMT), developed for the present study, were used to collect data.

The Test of Scientific Reasoning (TOSR), developed by Yezierski (2003), was used to determine the formal scientific reasoning ability of students. This test gives continuous scale scores ranging from 0 to 12. The internal reliability for this test scores is reported as 0.78 (Yezierski 2003). Yezierski reported a strong correlation of 0.80 between scores on the TOSR and formal reasoning skills, which are controlling variables, proportional reasoning, combinatorial reasoning, probabilistic reasoning, and correlation reasoning. The TOSR used in this study contained twelve items designed to assess students' use of a particular reasoning skill. The internal reliability for the TOSR scores in this study was 0.63.

The Purdue Visualization Test: Rotations (PSVT:R) was used for the pre-test. It is appropriate for use with adolescents and may be administered both in groups and individually. According to the test's developers, Bodner and Guay (1997), this test is among the spatial tests least likely to be confounded by analytic processing strategies. This test evaluates the subject's ability to rotate an image in their mind and to visualize the object in the new orientation. The PSVT:R format used had 20 questions. In each question, an object was pictured in one position and then it was shown in a second image, rotated to a different position. Participants were shown a second object and given five choices, one of which matched the rotation of the example object. They were asked to select the object that showed the same rotation as the example for that question. To restrict analytical processing, a time limit of 10 min for the 20-item version of this test was strictly enforced. Reliability for the PSVT:R scores was reported by Bodner and Guay (1997) using Kuder-Richardson 20 internal consistency test values of 0.80.

The Chemical Bonding Academic Achievement Test (CbAAT) was used in the present study to collect data. The CbAAT consists of 30 multiple-choice questions, with each question worth five points. This test was created by the researchers. The questions in the test were related to the basic concept in bonding, bond types, Lewis structures, bond energy, geometry structure of molecules, intermolecular and intra-molecular bonds, valence bond model, and molecular-orbital theory. This test was given to students who were not involved in the study but had previously taken the course in which the chemical bonding topics mentioned above had been taught. With respect to reliability, CbAAT was administered to a group of 45 students who had taken the General Chemistry-II course the year before. The KR20 was used to determine the reliability of CbAAT scores and the reliability coefficient was found ($\alpha = 0.83$). Moreover, to check the validity of the CbAAT developed the opinions of chemistry lecturers and researchers on the subject were taken into consideration. Researchers pointed out that the gains achieved with CbAAT related to the subjects of chemical bonding have been high in terms of measurement.

The Particulate Nature of Matter Test in Chemical Bonding (CbPNMT) was designed to determine understanding of the concepts relevant to chemical bonding. The CbPNMT consists of 11 open-ended questions. This is an instrument requiring the students to make drawings at molecular level and give explanations in response to questions. The questions in the test were related to the correct Lewis structures for any simple molecule or ion, testing ability to show covalent bond formation using Lewis symbols; predict, from its molecular shape and the electronegativities of the atoms involved, whether a molecule is polar (has a dipole); predict the polarities of bonds between any two atoms from their electronegativities; represent the hydrogen bonding in water (liquid), the attractive and repulsive forces acting between two atoms, and the formation of hydrogen molecule in terms of the valence bond theory; and construct the molecular-orbital energy-level diagram for a diatomic molecule predicting the bond order and magnetic properties. The categories of responses for the CbPNMT were established by a panel of experts. Responses given in terms of molecules, atoms, ions, and so on are classified as showing scientific (at molecular level) understanding. For CbPNMT, the students' written responses were analyzed and their levels of understanding of chemical bonding subjects at particulate level were determined. The responses from the CbPNMT post-test were evaluated in the following two categories: (1) scientific (at particulate level) understanding and (2) misunderstanding. The first category of responses included a part or the whole of scientific opinions related to the question. To examine and score the questions in an objective manner, we developed rubrics. For example, when the student illustrates the molecular-orbital energy-level diagram for one of three molecules, s/he receives five points. However, if the student fails to illustrate it, s/he receives zero points and the rest of his/her responses are not taken into consideration for question 11 (see Findings Relating to the Misunderstanding Category in the "Results" Section). If the student predicts the bond order for one of three molecules correctly, s/he receives two and a half points. And if the student refers to the magnetic properties for one of three molecules correctly, s/he receives two and a half points. Thus, rubrics were written for all the open-ended questions. The score for questions 1–10 ranges from 0 to 10 and for question 11 ranges from 0 to 30; hence the score for the CbPNMT ranges from 0 to 130.

The second category included statements that demonstrate misunderstanding. In the analyses of this category, drawings by students with non-scientific features were verbally grouped at question level individually in the first phase by the researcher. In the second phase, groups of answers from each student were compared and their consistency was measured. The percentage values of the expressions obtained from the drawings in this category, and samples from student drawings were given. Moreover, to ensure the validity of the CbPNMT developed by researchers, opinions of the chemistry lecturers and researchers on the subject were taken into consideration. Researchers have pointed out that the gains achieved with CbPNMT related to the subjects of chemical bonding have been high concerning measurement.

Procedure

Students from the experimental (AG and JG) and control groups studied the topic of chemical bonding during the same period of time in different ways (instructional methods). The same content was taught in all groups by the same teacher and the learning objectives were the same.

Three groups—one JG, one AG, and one CG—and one chemistry teacher participated in the study. In the implementation process, firstly, the TOSR, the PSVT:R, and the CbAAT were administered to all the groups of students as a pre-test to identify their formal scientific reasoning ability, their ability to rotate an image in their mind and to visualize the object in the new orientation, and their basic levels understanding of chemical bonding 2 weeks before the intervention. Secondly, the intervention phase was conducted.

As indicated in Fig. 1, the students in the jigsaw cooperative learning class were divided into six heterogeneous "home groups" since chemical bonding is divided into six subtopics. Each home group consisted of six students. Before the beginning of the instruction, the teacher gave information about learning objectives, the instruction process, rules for working in a cooperative group, group member roles, and assessment strategies. Each of the six subtopics was given to a home group. The students in the home groups were responsible for inquiring and preparing the information related to all of the subtopics. Students got together in their home groups; each group set an inquiry topic within a given unit and made a plan for investigation. During their studies, group members visited the library and used various chemistry books to prepare their assignment. Each group studied their subject out of and in class and groups completed their assignments in 1 week. Students met in their home groups and each member of the group was assigned a portion of the material to learn as an 'expert'. The home groups then broke apart, like pieces of a jigsaw puzzle, and the students moved into jigsaw groups consisting of members from the other home groups who were assigned each subtopic. These subtopics and the jigsaw groups are shown in Fig. 1. After the assignment of each topic, students met others in the class who were responsible for the same topic of study. Students discussed and reviewed their topics, often asking the instructor for clarification. Within this discussion groups, the students decided on the best approach to take to deliver material to their respective group. These discussion groups met for about 1 h per class before presenting their "piece" of information to the groups. Once the students had mastered their respective material, they returned to their home group to present this information to their group members. Each student was responsible for a portion of the unit; hence, all members of each group covered the unit as a whole. It was then the students' responsibility to be able to present in a clear and concise manner their respective material. All activities were completed by students under the guidance of the teacher. While students were discussing in their small groups, the teacher visited all the groups and asked guiding questions to lead students in appropriate directions. All the cooperative groups prepared their own reports after the teaching and learning activities were completed. Each group was given 2 h to present their work to the rest of the class and discuss it. During this presentation, the group answered questions from the class. All groups completed their topics in 5 weeks.

The computer animation instruction scheme in the current study is a mixture of whole-class presentation, discussions among the teacher and students, and visualization activities using the animations. The instruction emphasized direct guidance and presentation, clear explanations of important concepts to the students given by teachers in the chemistry classroom, and explaining the step-by-step process of chemical bonding through a computer-animated presentation. The computer animations used in the animation group were obtained from various web addresses. These animations were shown after arrangement by an expert from the department of computer and teaching technologies. Then the researcher spent the first 5 min of the lesson asking questions to the class, in order to determine the students' previous knowledge on the subject. Later, the subject was taught and the related animations were shown to the class for 35 min. The whole-class presentation was implemented using the combination of a high-speed laptop computer and a high-resolution LCD projector to display the animations on a large screen in front of a whole class. Class discussions between the teacher and the students and among students were also embedded in this teaching format. After the presentation of the animations, questions related to the subject were asked for 10 min. Parts of the subjects not fully understood were determined according to the answers and these parts were covered again using the animations related to the subject. For each step, students were engaged in a class discussion and animation sequences over a course hour.

Six main categories of animations (Table 1) were used in lectures during the coverage of the unit on chemical bonding. Animations included figures, graphs, three-dimensional presentations, and problem-solving exercises to supplement the theoretical content knowledge.

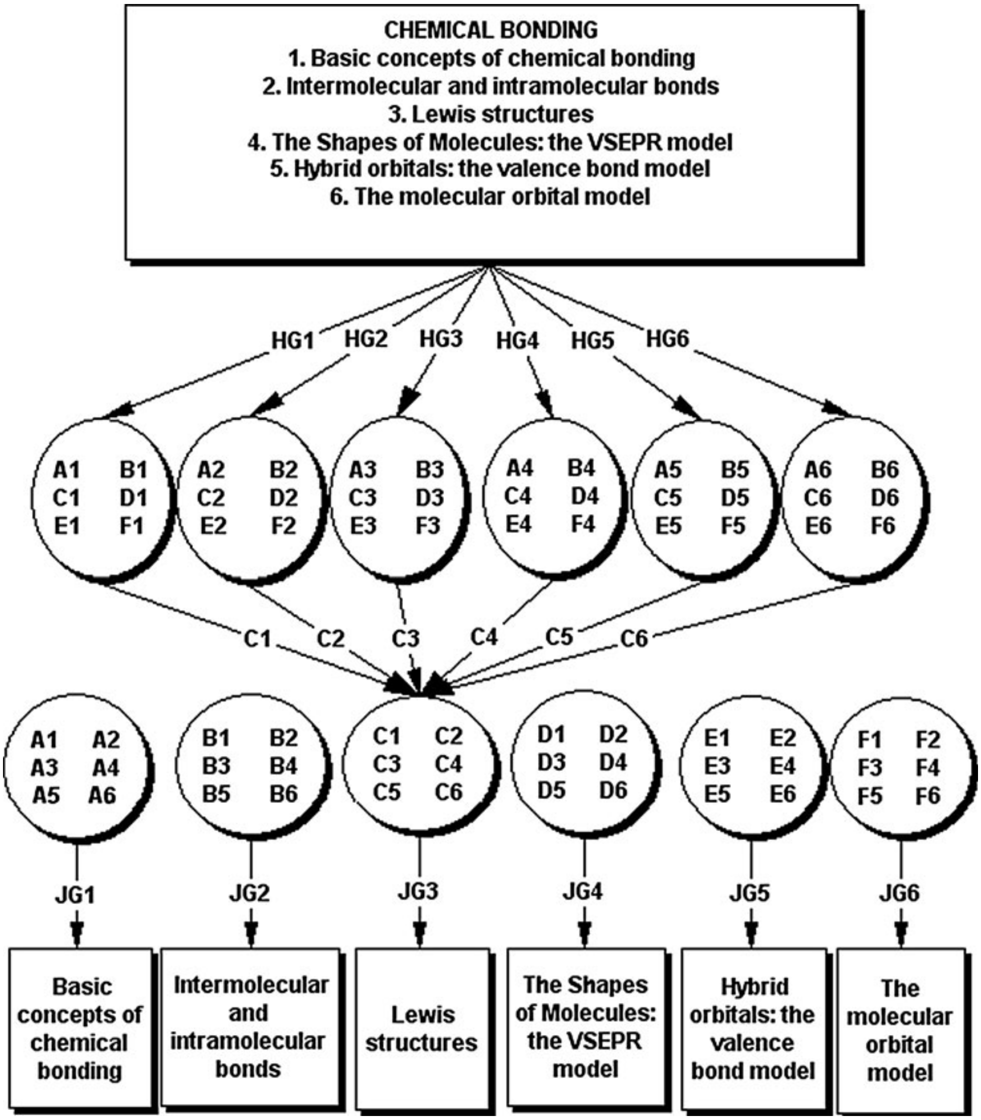

Fig. 1 Subtopics of the chemical bonding unit and home groups (*A1*, *A2*, *A3* etc. Represent Individual Students from a Group; *HG1*, *HG2* etc. Represent the home groups; and *JG1*, *JG2* etc. Represent the jigsaw groups) and forming of jigsaw groups from home groups

Table 1 Topics and visualization activities in chemical bonding

Chemical bonding topics	Animations used
1. Basic concepts of chemical bonding	
1.1. What is a chemical bond?	Electron shells and chemical reactivity
1.2. Why do chemical bonds form?	Covalent & ionic bonds
1.3. Bond energies	Polarity and hydrogen bonding
1.4. Bond lengths	Interactive periodic table
1.5. Ionization energy	The periodic table: elements and bonding
1.6. Electron affinity	Formation of compounds from atoms
1.7. Electronegativity	
2. Types of bonding and intermolecular forces	
2.1. Ionic bonding	Ionic, covalent, and metallic bonding
2.2. Covalent bonding	Ionic, covalent, and hydrogen bonding exercises
2.3. Metallic bonding	Van der Waals forces
2.4. Van der Waals forces	Intermolecular forces
2.4.1. Hydrogen bonding	
2.4.2. Dipole–dipole forces	
2.4.3. London dispersion forces	
3. Lewis dot structures	
3.1. Drawing Lewis dot structure	Drawing lewis dot structure
3.2. Formal charge	Definition of formal charge
3.3. Resonance structures	
3.4. Exceptions to the octet rule	
4. The shapes of molecules: the VSEPR model	
4.1. Electron pair repulsion	Molecular shape and polarity
4.2. Diagonal and trigonal coordination	Arrangement of electron pairs and molecular
4.3. Tetrahedral coordination	Shapes according to VSEPR model
4.4. Tetrahedral coordination with lone pairs	
4.5. Atoms bonded to five atoms	
4.6. Octahedral coordination	
5. Hybrid orbitals: the valence bond model	
5.1. What are hybrid orbitals?	Hybridization of atomic orbitals
5.2. Diagonal bonding: sp-hybrid orbitals	Chemical bonds formed due to overlap of atomic orbitals
5.3. Trigonal (sp2) hybridization	Sigma and Pi Bonds
5.4. Tetrahedral (sp3) hybridization	
5.5. Conjugated double bonds	
5.6. Hybrids involving d orbitals	
5.7. Limitations of the hybrid model	
6. The molecular orbital model	
6.1. Molecular orbitals	Molecular orbitals diagrams for first- and second-row diatomic molecules
6.2. The hydrogen molecule ion molecular orbitals	The formation of the bonding and antibonding
6.3. Bonding and antibonding molecular orbitals	
6.4. Molecular orbital diagrams	
6.5. Diatomic molecules containing second-row atoms	
6.6. Sigma and pi orbitals	

Two print-screen views of the arrangement of electron pairs and molecular shapes according to the VSEPR model that were taken from the Internet are given in Fig. 2 as an example. In these animations, the effects of non-bonding electron pairs on the shapes of CH_4, NH_3, and H_2O molecules were shown to students (Fig. 2a). Electron-group arrangements are shown on the left and molecular geometries on the right.

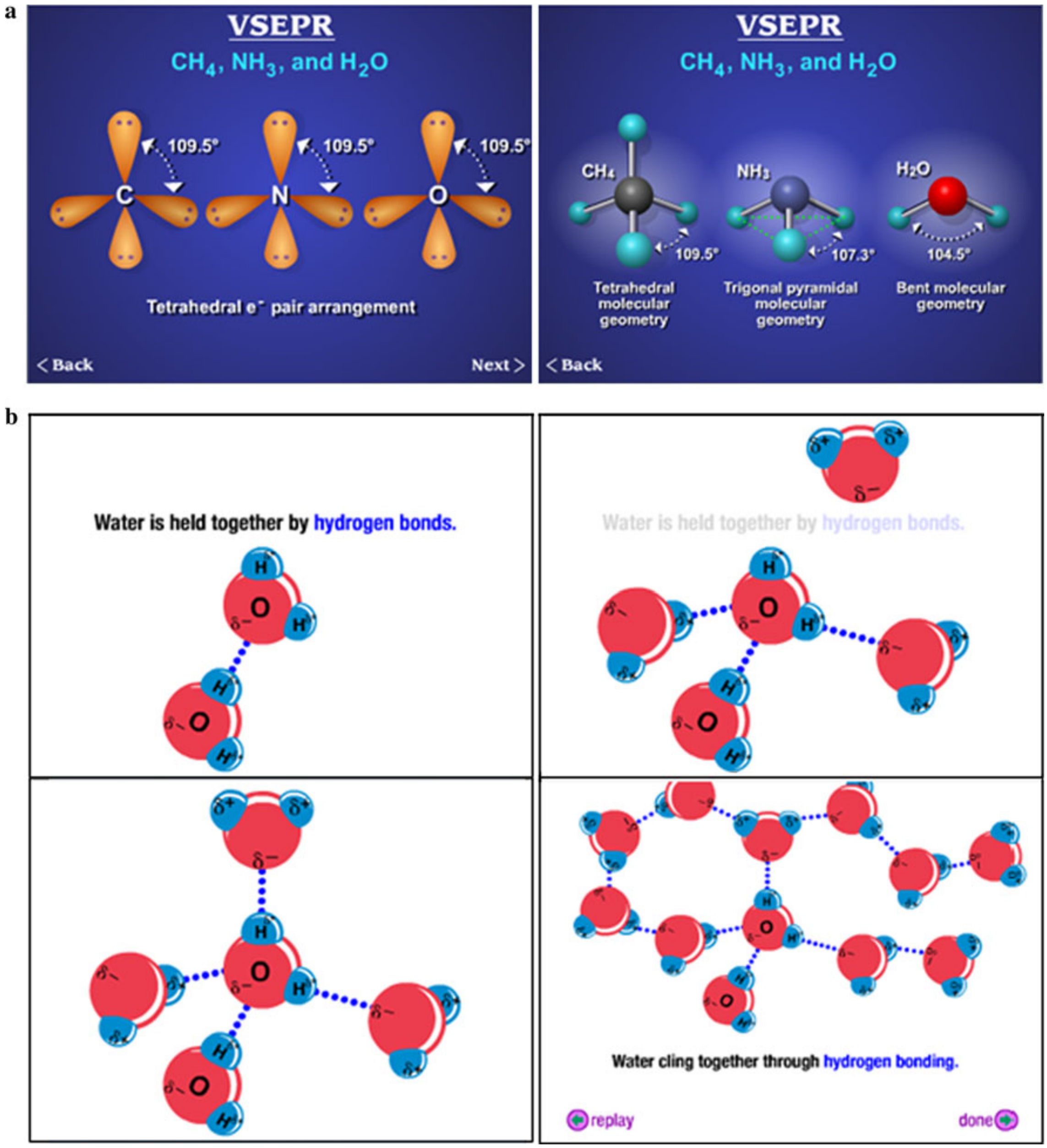

Fig. 2 **a** Effect of non-bonding electron pairs on molecule shape (Available at http://www.kentchemistry.com/links/bonding/vsepr.htm). **b** Formation and orientation of the hydrogen bonds between H_2O molecules. (Available at http://www.northland.cc.mn.us/biology/biology1111/animations/hydrogenbonds.html)

In another animation, the formation of hydrogen bonds is shown step by step, and these are dynamic animations in which the students are able to see the movement of the H_2O molecules during the formation of hydrogen bonds (Fig. 2b).

In the CG, the students were taught by a teacher-centered approach (traditional teaching method) involving the teacher's explanations of the concepts related to chemical bonding using the textbook for examples and illustrations in a 'talk-and-chalk' type lessons. About 75–80 % of the class hour covered the teacher's explanations related to chemical bonding. Some concepts were discussed after the teacher's explanation. Generally the teacher wrote the concepts on the board and then explained them; students listened and took notes as the teacher lectured on the content. The teacher passed out the problem-solving exercises including mathematical and conceptual questions related to chemical bonding to students. While the students were solving the problems requiring written responses, the teacher walked around the classroom and helped them if required. The students had the opportunity to ask questions during this process. Such a teaching approach used in the

CG generally required students to sit passively and did not actively engage them much in learning. They sometimes raised their hands to answer questions. The students became listeners, the teacher gave out the facts and defined important ideas, and students' participation was often limited to listening to the teacher. Teacher offers some learning resources in the traditional teaching method, but following these sources by the students are considered to be their own individual responsibilities.

This research was performed as a routine part of a general chemistry course. The additional information which contains that the students are the part of this study was not be given to the students in each group. The process of teaching was prepared during two different days in a two-hour lesson according to the weekly General Chemistry course programme pre according managed by the faculty at the beginning of the academic semester. The teacher had prepared his planning including the same course content in accordance with the process goals/achievements at the beginning of training course. As a result of accepting this application as a part of the course the students need to be successful in the final exam which contains these including the research issues and other subjects to pass the final lesson of the semester. In this context, the teacher has tried to teach the basic content of the chemical bonding to all of the students equally. However, education was carried out using different techniques for similar contents in treatment groups by the same teacher. The teacher as a researcher has taken place in the process of teaching the other issues of courses as a teaching assistant to the process of teaching other subjects in the general chemistry course in the same groups' classes. Time unit for the teaching of chemical bonds in each group were equal. However, in the process of teaching students' times which was spent for their extracurricular activities out of class to fulfill their responsibilities has varied according to each others. These effects were evaluated as individual differences as being applied to students in all groups. During this process, students' performances were observed and the studies were directed according to the feedback received from them. At the end of the study, the CbAAT and the CbPNMT were administered to treatment groups of students as a post-test 1 week after the intervention.

Analysis of the Data

Descriptive statistics (sample sizes, means, and standard deviations) for TOSR, PSVT: R, pre- and post-CbAAT, and post-CbPNMT scores were calculated for the groups. The equivalence of the research groups at pretests was examined by the use of one-way ANOVA of the scores obtained from the TOSR, PSVT: R, and pre-CbAAT.

To investigate the effects of the jigsaw cooperative learning and computer animation instruction on students' achievements in terms of chemical bonding concepts and their understanding of chemical bonding in the particulate nature of matter, a one-way multivariate analysis of covariance (MANCOVA) on the CbAAT and CbPNMT posttest scores with TOSR, PSVT: R, and CbAAT pretest scores as the covariates was conducted to see if there was a significant difference between the experimental groups and the control group on each set of the dependent variables. When a MANCOVA was found significant, the investigation was followed up with a univariate ANCOVA on each of the dependent variables to see if there was a significant difference between the experimental groups and the control group. MANCOVA asks if there are statistically significant mean differences among groups after adjusting the newly created dependent variable for differences on one or more covariates. If the one-way MANCOVA is significant, follow-up analyses can assess whether there are differences among groups on the population means for certain dependent variables and for particular linear combinations of dependent variables. A popular follow-up approach is to conduct one-way ANCOVAs. If any of these ANCOVAs yield significance and the factor contains more than two levels, additional follow-up tests are performed. Follow-up tests were conducted to evaluate pairwise differences among these adjusted means. The Holm's sequential Bonferroni procedure was used to control for Type I error across the three pairwise comparisons (Green and Salkind 2005; Tabachnick and Fidell 2006).

In addition to ANCOVA, we calculated Cohen's effect sizes to determine the magnitude of the treatment effect. The effect size index eta squared (η^2) or f value was used since it is more appropriate for the analysis of variance or covariance. According to Cohen's rough characterization, $f = 0.1$ is deemed a small effect size, $f = 0.25$ a medium effect size, and $f = 0.4$ a large effect size (for interpreting η^2, 0.01 = "small," 0.059 = "medium," and 0.138 = "large") (Cohen 1988). Effect size was calculated with the formula $f = [\eta^2/1-\eta^2]^{1/2}$.

Results

Means and standard deviations for TOSR, PSVT-R, and pre-CbAAT scores for the experimental and control groups are given in Table 2. It is seen that students' mean scores for the TOSR and PSVT-R were similar but their mean scores for the pre-CbAAT were not similar between the experimental and control groups.

In order to determine whether there was a significant difference between the groups before the study according to the scores obtained from the TOSR, PSVT-R, and

Table 2 Descriptive statistics for TOSR, PSVT-R, and pre-CbAAT Scores

Groups (N)	TOSR Mean (SD)	PSVT-R Mean (SD)	Pre-CbAAT Mean (SD)
CG (40)	6.68 (1.845)	9.58 (3.761)	40.62 (16.725)
JG (36)	6.58 (1.713)	10.61 (3.433)	49.44 (18.039)
AG (39)	6.31 (1.673)	10.49 (3.235)	53.72 (16.211)

pre-CbAAT, one-way ANOVA was performed and the results are presented in Table 3.

The results of ANOVA showed no significant difference among the TOSR scores of the students in the treatment groups ($F_{(2,112)} = 0.469$; $p > .05$) or the PSVT-R scores ($F_{(2,112)} = 1.024$; $p > .05$). However, significant mean differences were found among the pre-CbAAT scores ($F_{(2,112)} = 6.110$; $p < .05$). LSD, a post hoc test, was applied in order to determine in which groups there was such a difference. As a result of the LSD analysis, pre-CbAAT scores of both the AG and JG were observed to be higher than those of the CG ($X_{AG} = 53.72$; $X_{JG} = 49.44$; $X_{CG} = 40.62$). According to the results of ANOVA in Table 3, the students involved in the research have similar characteristics in terms of scientific reasoning abilities and spatial abilities, whereas they have different levels of understanding of chemical bonding. This reflects the different backgrounds of the treatment group students in respect to chemical bonding before the intervention.

With regard to achievement and understanding of chemical bonding in the particulate nature of matter, a one-way multivariate analysis of covariance (MANCOVA) on the post-CbAAT and CbPNMT scores with TOSR, PSVT-R, and pre-CbAAT scores as the covariates was conducted to see if there was a significant difference among the treatment groups on each set of the dependent variables. The results of the MANCOVA for the students' post-CbAAT and CbPNMT scores are shown in Table 4.

One-way multivariate analyses of covariance (MANCOVAs) and one-way univariate analyses of covariance (ANCOVAs) were conducted to answer research questions two and three. An alpha level of .05 was used for all statistical tests. Because the researcher was not necessarily concerned about Type I error, an alpha level of $\alpha = .05$ was chosen by convention. Covariates were used to reduce the error variances on the dependent variables and to increase statistical power. Even though the sample sizes were equal, the homogeneity of variance assumption was tested using Levene's statistic. The observed value was $F_{(2,112)} = 2.673$, $p > .05$ for post-CbAAT scores indicating equivalency of variances across the groups. However, The observed value was $F_{(2,112)} = 9.578, p < .05$ for CbPNMT scores. Because this is significant, we know that the assumption of homogeneity of variances is violated for CbPNMT scores. However, since groups are nearly equal (36, 39 and 40) in size; the test should not be strongly affected by this violation. MANCOVA/ANCOVA as being robust with respect to moderate violations of variance homogeneity, provided the experimental condition sample sizes are equal and greater than five (Leech et al. 2005).

The MANCOVA indicated significant main effects for the treatments (Wilks' Lambda = 0.694, F (4, 216) = 10.809, $p < .05$). This means that there was a significant mean difference among the three treatment groups' students with respect to the students' post-CbAAT and CbPNMT scores. Therefore, follow-up ANCOVA was needed to decide which dependent variable is responsible for this significance. Table 5 contains the summary of the ANCOVA comparing the mean scores of the student performances in the experimental and control groups with respect to post-CbAAT and CbPNMT scores, respectively.

Table 5 shows a significant difference among the adjusted mean scores of both post-CbAAT ($F_{(2,109)} = 17.078$; $p < .05$; $\eta^2 = 0.24$; f = 0.56) and CbPNMT

Table 3 ANOVA results for TOSR, PSVT-R, and pre-CbAAT scores

Dependent variable	Source	Sum of Squares	*df*	Mean square	F	*p*
TOSR	Between groups	2.863	2	1.431	.469	.627
	Within groups	341.833	112	3.052		
	Total	344.696	114			
PSVT-R	Between groups	24.917	2	12.459	1.024	.362
	Within groups	1,362.074	112	12.161		
	Total	1,386.991	114			
Pre-CbAAT	Between groups	3,522.360	2	1,761.180	6.110	.003
	Within groups	32,284.161	112	288.251		
	Total	35,806.522	114			

Table 4 The results of the MANCOVA for the students' post-CbAAT and CbPNMT scores

	Value	F	Hypothesis *df*	Error *df*	Sig.	Partial η^2
Wilks' lambda	.694	10.809	4.000	216.000	.000	.167

Table 5 The results of the ANCOVA for the students' post-CbAAT and CbPNMT Scores

Dependent variable		Sum of squares	*df*	Mean square	F	Sig.	Partial η^2
Post-CbAAT	Contrast	9,247.605	2	4,623.802	17.078	.001	.239
	Error	29,512.130	109	270.753			
CbPNMT	Contrast	18,603.486	2	9,301.743	12.641	.001	.188
	Error	80,205.492	109	735.830			

($F_{(2,109)} = 12.641$; $p < .05$; $\eta^2 = 0.19$; $f = 0.48$) of the students in the treatment groups, with high effect size. All effect sizes were above large ($f > 0.4$). An effect size of 0.4 is considered large. A significant difference among the means for each dependent variable indicates that post hoc pair-wise comparisons should be conducted to identify which instructional methods were effective.

Table 6 presents the unadjusted and adjusted means of post-CbAAT and CbPNMT scores for each instructional treatment and the control group. The adjusted mean of post-CbAAT for the AG and JG is larger than that for the CG. Moreover, the adjusted mean of CbPNMT for the AG is larger than that for each of the other instructional treatment groups (JG and CG) and also mean for the JG is larger than that for the CG. In order to determine whether the difference in means was statistically significant, further analysis using the Bonferroni post hoc procedure was conducted.

Paired comparisons with modified Bonferroni correction revealed significant differences for adjusted means of post-CbAAT between the AG and CG (mean difference = 21.942; $p < .05$) and between the JG and CG (mean difference = 16.760; $p < .05$) but no significant difference between the AG and JG (mean difference = 5.181; $p > .05$). In addition, significant differences were found for adjusted means of CbPNMT between the AG and each of the other groups (mean difference = 32.471 and mean difference = 16.143; $p < .05$ for the JG and CG, respectively) and between JG and CG (mean difference = 16.328; $p < .05$). This indicates that the instructional methods of computer animation and jigsaw cooperative learning were more effective in improving students' achievements in chemical bonding concepts and their understanding of chemical bonding in the particulate nature of matter than the traditional teaching method. Furthermore, computer animation and jigsaw cooperative learning show similar effects with respect to the students' achievements in chemical bonding. However, the computer animation method was more effective in improving students' understanding of chemical bonding in the particulate nature of matter than the jigsaw cooperative learning.

Findings Relating to the Misunderstanding Category

The answers given by the students in the treatment groups showing misunderstanding of the questions on the CbPNMT, including molecular level drawings except scientific ones (which are categorized in the MU part) and some of the samples of these drawings are shown below. Questions 1 and 2 dealt with drawing Lewis dot structures for NaCl and $AlCl_3$, respectively. The written expressions obtained from the students' drawings for Questions 1 and 2 of the CbPNMT and the percentages of these expressions are given in Table 7 and some drawings are given in Fig. 3.

As can be seen from Table 7, 72 % of CG students, 46 % of JG students, and 26 % of AG students seemed to

Table 6 The unadjusted and adjusted means of the students' post-CbAAT and CbPNMT scores for students per instructional method

Groups (N)	Post-CbAAT		CbPNMT	
	Unadjusted mean	Adjusted mean	Unadjusted mean	Adjusted mean
CG (40)	70.63	76.182[a]	21.81	24.377[a]
JG (36)	93.89	92.942[a]	41.18	40.705[a]
AG (39)	102.95	98.123[a]	59.04	56.848[a]

[a] Covariates appearing in the model are evaluated at the following values: TOSR = 6.52, PSVT-R = 10.21, pre CbAAT = 47.83

Table 7 The percentages of written expressions obtained from students' drawing related for the MU category of questions 1 and 2 of the CbPNMT

Representative responses (students' expressions)	CG	JG	AG
Students' drawings show that a chemical bond is formed between Na and Cl atoms through electron sharing instead of the complete transfer of electrons from one atom to another (Fig. 3)	72	46	26
Students' drawings show that a chemical bond is formed between Al and three Cl atoms through electron sharing instead of the complete transfer of one or more electron from one atom to another (Fig. 3)	84	65	33

Percentages were calculated on the basis of the number of students in each group given in the table

have problems in understanding the ionic bonding that occurred between Na and Cl atoms. Similarly, 84 % of CG students, 65 % of JG students, and 33 % of AG students did not understand the ionic bonding that occurred between Al and three Cl atoms. These results suggest that the CG and JG students gave a larger percentage of responses in the MU category than the AG students did for these tasks.

Questions 3 and 10 of the CbPNMT were related to the representation of hydrogen bonding in liquid water (question 3) and the formation of a hydrogen molecule in terms of the valence bond theory (question 10). The written expressions obtained from the students' drawings for these questions and the percentages of these expressions are given in Table 8 and some drawings are given in Fig. 4.

Table 8 shows that only 33 % of CG students, 22 % of JG students, and 13 % of AG students gave responses in the MU category to the question related to the formation of intermolecular hydrogen bonds between water molecules. A lower portion of students in the treatment groups did not understand that hydrogen bonds in water are formed between the hydrogen atom of one water molecule and the oxygen atom of another water molecule. This happens with hydrogen atoms attached to oxygen, nitrogen, or fluorine, due to the high electronegativity of these atoms.

At the same time, 40 % of CG students and 50 % of JG students showed misunderstanding related to the formation of hydrogen molecules in terms of the valence bond theory (question 10), whereas all of the students in the AG understood the formation of hydrogen molecules in terms of the valence bond theory correctly. These responses revealed that CG and JG students did not understand the relationship between internuclear separation and the energy of the system during bond formation in terms of the valence bond theory.

Question 11 of the CbPNMT was related to the construction of a molecular-orbital energy-level diagram for a diatomic molecule (for diboron, B_2; dinitrogen, N_2; and dioxygen, O_2) predicting the bond order and magnetic properties. The written expressions obtained from the students' drawings for this question and the percentages of these expressions are given in Table 9 and some drawings are given in Fig. 5.

As seen in Table 9, 86 % of CG students, 61 % of JG students, and 37 % of AG students gave answers in the MU category to question 11. Based on these results, it is evident that most of the students in the CG did not understand bond theories because their responses revealed that they used atomic orbitals instead of molecular orbitals. That is, the vast majority of the students in the experimental groups partially grasped the concept of the molecular orbital theory. About 33 % of JG students and 29 % of AG students think that the valence electrons from the starting atoms are randomly distributed in the new molecular orbitals, whereas these electrons are occupied in the molecular orbitals in accord with the Aufbau principle, which states that molecular orbitals are filled starting with the lowest energy, and Hund's rule, which states there are several molecular orbitals with equal energy and the electrons fill one molecular orbital at a time. At the same time, these students in the experimental groups did not consider that the relative energy levels of molecular orbitals of Li_2 to N_2 are different from those of O_2 and F_2. The explanation for the difference comes from the consideration of hybrid atomic orbitals. Because the 2s energy levels and 2p energy levels for Li to N are relatively close, the 2s orbitals are influenced by the 2p orbitals. This influence makes the bonding orbitals stronger than and the antibonding orbitals weaker than those formed by pure 2s orbitals. This process is called s-p mixing. Due to s-p mixing, the σ_{2p} orbital is weakened, and the σ^*_{2p} is also affected. These effects cause the relative order to change.

Discussion and Implications

In this study, we examined the students' learning achievements by applying three different teaching methods to the chemical bonding unit in a general chemistry course. Thus, the students' scientific thinking skills, spatial visualization abilities, academic achievements, and understanding of chemical bonding in the particulate nature of matter have been identified. Based on the data obtained from tests performed before and after the study the following conclusions have been reached.

The TOSR was used to identify potential differences in the cognitive skills of students and to test whether this extraneous effect influenced their learning. According to

Fig. 3 Some students' drawings in the misunderstanding category of questions 1 and 2 of the CbPNMT

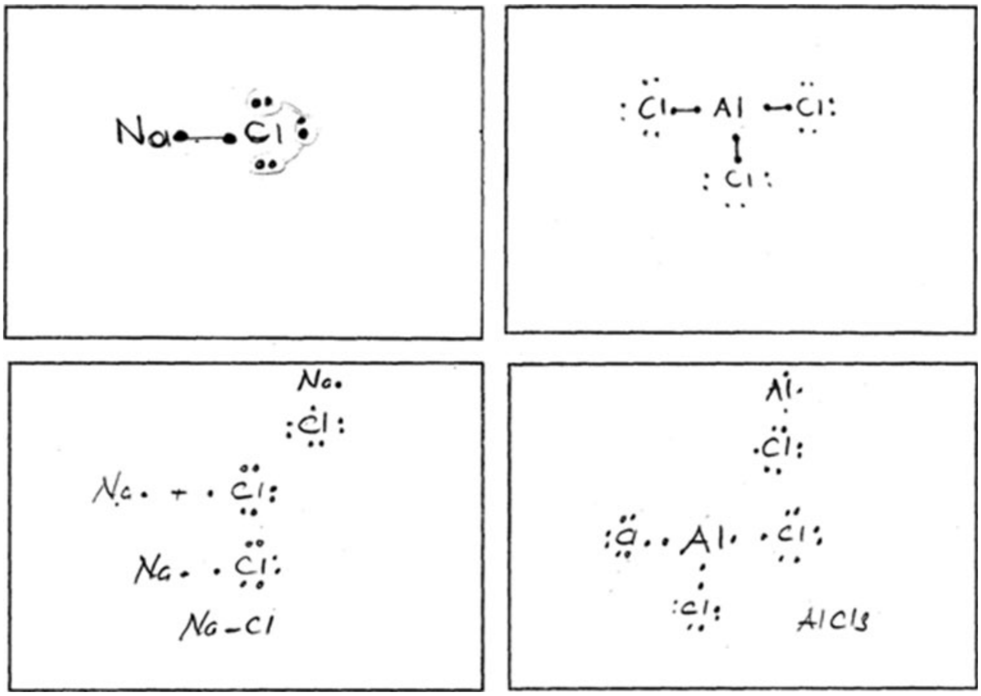

Table 8 The percentages of written expressions obtained from students' drawings for the MU category of questions 3 and 10 of the CbPNMT

Representative responses (students' expressions)	CG	JG	AG
Students' drawings show that intermolecular hydrogen bonds in water are formed between a hydrogen atom of one molecule and a hydrogen atom of another molecule (Fig. 4)	33	22	13
Students' drawings show that two hydrogen atoms HA and HB (H–H) are a large distance from each other, and there is no interaction between them when the energy of the system is minimum during the formation of a hydrogen molecule	40	50	0

Percentages were calculated on the basis of the number of students in each group given in the table

Fig. 4 Some students' drawings in the misunderstanding category of question 3 of the CbPNMT

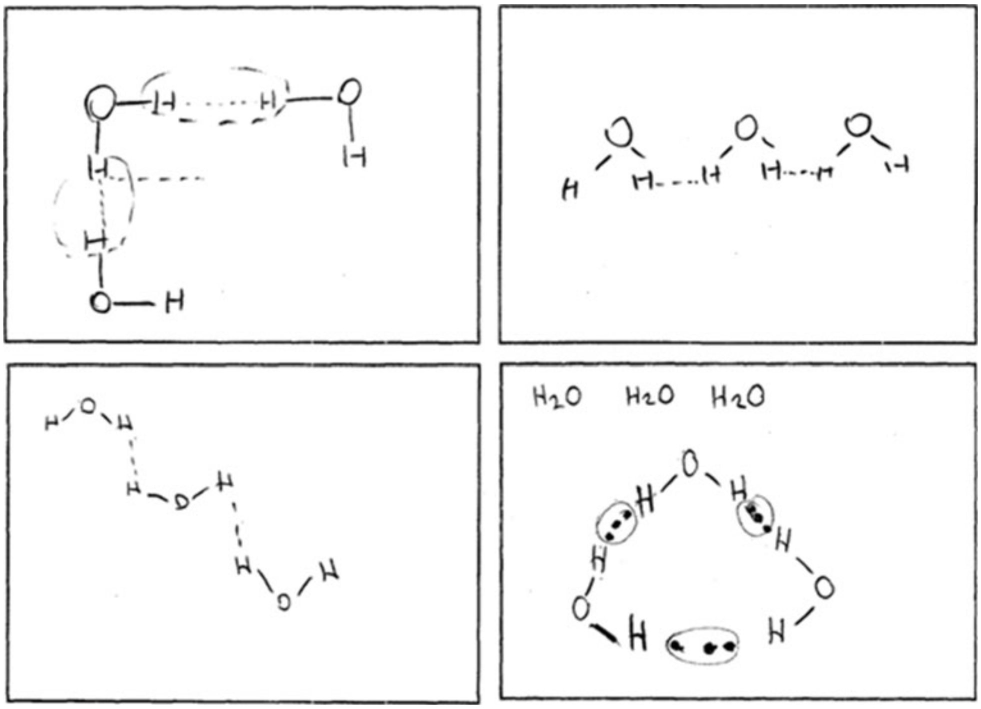

Table 9 The percentages of written expressions obtained from students' drawings for the MU category of question 11 of the CbPNMT

Representative responses (students' expressions)	CG	JG	AG
Students represented the atomic orbital electron configuration instead of the molecular orbital electronic configuration	86	28	8
Students violated the Aufbau principle when they filled the molecular orbitals with electrons	0	0	8
Students violated Hund's rule when they filled the molecular orbitals with electrons (Fig. 5)	0	0	8
Students violated s-p mixing for diboron and dinitrogen or no s-p mixing for dioxygen (Fig. 5)	0	33	13

Percentages were calculated on the basis of the number of students in each group given in the table

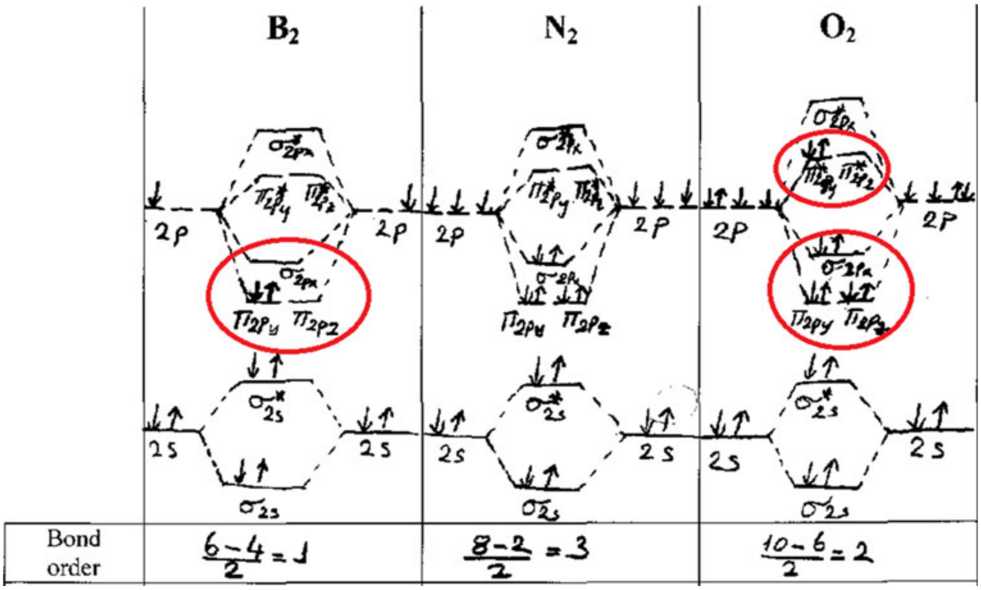

Fig. 5 Some students' drawings in the misunderstanding category of question 11 of the CbPNMT

the results of the TOSR, of the students who participated in the study scientific thinking skills were found in approximately 65 % (Table 2). According to the data obtained from this test, there were no significant differences between the groups (Table 3). A high level of scientific thinking skills increases the learning capacity of students, allows them to be active during courses, and develops their sense of taking responsibility during self-learning periods. Moreover, a high level of scientific thinking skills encourages students to learn logical thinking as well as science, helps them to ask reasonable questions and to find acceptable answers for these questions, and it has an effect on learning to solve problems faced by the students during their daily life (Abdullah and Shariff 2008; Bektasli 2006). In this study, the data obtained from the test of scientific thinking were compatible with the results reported by Reid and Serumola (2007); Al-Ahmadi (2008), and Al-Ahmadi and Oraif (2009), but not with those reported by Lloyd and Howe (2003) and Unutkan (2006).

The main objective of the implementation of the PSVT-R was to examine whether students' spatial visualization ability has an impact on their learning of chemistry at macroscopic, symbolic, and microscopic levels. Therefore, the effect of differences between the spatial abilities of the students who participated in the study was selected as covariates. From the PSVT-R scores obtained in this study, students achieved an average score of 10.2 (SD = 3.48) on the 20-question PSVT-R test (Table 2). One way ANOVA showed no significant differences in spatial visualization between the groups; in the other words, the three groups selected had similar characteristics in terms of their spatial abilities (Table 3). Previous studies have shown that high-spatial ability learners are more successful in understanding the formation of bonds and in determining the geometric shapes of molecules (Barnea and Dori 2000; Bodner and Guay 1997; Wu and Shah 2004). The results of this test, compared with the results of other studies, i.e., by Bodner and Guay (1997); Yang, Andre and Greenbowe (2003) and Black (2005), are similar, but data obtained by Hart (2003); Bektasli (2006); Ferguson (2008), and Keehner et al. (2008) are found to be high.

The effectiveness of any teaching method needs to be evaluated in a specific context because teaching and learning processes are complex, involving many cognitive, affective, and environmental variables. The spatial abilities and the scientific reasoning of the undergraduates became a research interest after encountering studies in the science education literature. Spatial abilities were linked to the mastery of chemistry content by a number of studies (Bodner and Guay 1997; Williamson and Jose 2008; Wu and Shah 2004). There are many studies reporting that logical thinking plays a major role in students' performance in science (Tsitsipis et al. 2010). Visual spatial ability and logical thinking play important roles in the understanding of graphical representations (Bektasli 2006). Thus, these cognitive variables might also be potential predictors of students' achievements in chemical bonding concepts and their understanding of the particulate nature of matter.

Our research findings showed that the students that participated in this study had similar characteristics in terms of their scientific reasoning ability and spatial abilities, but their levels of understanding of the subjects in chemical bonding differed from each other before the study (Table 3). Therefore, the effect of differences between the cognitive variables (scientific reasoning and spatial ability) and the initial understandings levels of the students who participated in the study were selected as covariates. Those students' achievements in chemical bonding concepts and their understanding of chemical bonding in the particulate nature of matter varied significantly after the treatment.

This study indicates that the computer animation method and jigsaw cooperative learning were more effective in improving students' achievements in chemical bonding concepts and their understanding of chemical bonding in the particulate nature of matter than the traditional teaching method. These results are consistent with those of previous studies (Abdullah and Shariff 2008; Doymus et al. 2010; Frailich et al. 2009; Özmen et al. 2009). The reason why the computer animation method was more successful than the traditional teaching method is that animations group students were not only provided with animations but also given treatment included pre-questions, lecture, post-animation questions and answers, discussions, and re-teaching. Thus, the use of animations in teaching science concepts made a significant difference to the students' achievement. The computer animation instruction scheme in the current study is a mixture of whole-class presentation, interactive discussions among the teacher and students, and visualization activities using the animations. The instruction emphasized direct guidance and presentation, clear explanations of important concepts to the students given by teachers in the chemistry classroom, and explaining the step-by-step process of chemical bonding through a computer-animated presentation.

In addition, consistent with Paivio's dual coding theory of learning from animation, the animations in the present study were best when paired with appropriate verbal support (class discussion) because of the increase in both representational and referential encoding. Therefore, these instructional uses of animation could be described as "learning-by-viewing" approaches (Schank and Kozma 2002). According to studies in the literature, when the animation is played, the viewer can see representations of several dynamic chemical and physical processes and these visualizations help students overcome the learning barrier to visualize and understand how complex dynamic chemical processes occur (Kelly and Jones 2007; Rotbain et al. 2008; Tasker and Dalton 2006).

The fact that students in the jigsaw cooperative learning group were more successful than those in the traditional teaching group demonstrates that students had the chance to contribute their knowledge on the subjects as they did research and benefited from previous research, and they took part in the learning process actively in both in-class and out-of-class discussions. In this study, because of the students in jigsaw group who are accepted as in the position of both the learner and instructor they has put in more effort to spend time for learning out of class and investigating and studying on the extra resource extra-curricular work in order to fulfill these responsibilities for their time and resources than the students in the control and animation group. In the previous research, it was reported that cooperative learning led students to research from different sources and reconstruct their knowledge according to their own cognitive nature (Hanze and Berger 2007; Hennessy and Evans 2006; O'Leary and Griggs 2010; Souvignier and Kronenberger 2007). The jigsaw cooperative learning procedure in this study 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. Jigsaw cooperative learning can be very effective because students can establish a supportive, comfortable learning environment. They can be more actively engaged in the content of the course, and eventually they can experience greater gains in mastering the course content, which could translate into improved grades. An important part of the cooperative learning experience for most students is learning how to function successfully in a group (Doymus 2008; Colosi and Zales 1998). Several very significant interactions occur when students are engaged in cooperative 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 et al. 2007).

The computer animation method and jigsaw cooperative learning show similar effects with respect to the students' achievements in chemical bonding. However, the instructional computer animation method had a greater effect on students' understanding of chemical bonding in the particulate nature of matter than the jigsaw cooperative learning. For this reason, chemistry teachers should supplement the instruction of difficult chemistry units with animations that show the molecular level.

According to the CbPNMT results, students' high levels of misunderstanding show that there were problems in the teaching of chemical bonding in the particulate nature of matter. The results revealed that animations and static drawings were not sufficient for the students to understand chemical bonding in the particulate nature of matter. For the elimination of these insufficiencies, it was suggested that some animations representing ionic bond formation, hydrogen bonding in water (liquid), formation of molecules in terms of the valence bond theory, and the molecular-orbital energy-level diagram at the molecular level should be developed and their effects should be investigated.

This study indicates that students do not learn science concepts by traditional teaching methods as expected. Because of this, teachers have to consider alternative teaching approaches such as computer animation and jigsaw cooperative learning. In conclusion, for students to be more successful in learning the subjects in chemistry at the macroscopic, microscopic, and symbolic levels they should participate in group research rather than studying alone and they should be supported by animations that present the molecular level in class.

Acknowledgments This paper is part of doctoral dissertation submitted to the Institute of Natural and Applied Sciences, Department of Primary Education, Atatürk University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy, July 2010.

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