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Full Length Research Paper

Constructing models in teaching of chemical bonds: Ionic bond, covalent bond, double and triple bonds, hydrogen bond and molecular geometry

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Studies in chemistry education show that chemistry topics are considered as abstract, complicated and hard to understand by students. For this reason, it is important to develop new materials and use them in classes for better understanding of abstract concepts. Moving from this point, a student-centered research guided by a teacher was conducted by constructing models for teaching chemical bonds. A one-group pre-test – post-test design was used in the study (weak experimental design). A study guide was prepared on the topic of chemical bonding and was used to teach the topic to freshman students in General Chemistry II class. An achievement test on chemical bonding was taken by students before and after the study. Statistical analysis of the results has shown that the study guide enhanced students' understanding of chemical bonding concepts. Additionally, some misconceptions in the topic reported in literature were not observed in the study group.

Key words: Chemistry education, modelling, ionic bond, covalent bond and hydrogen bond.

INTRODUCTION

In their study concerning the sturctures and properties of molecular and ionic compounds, Butts and Smith (1987) have found that students confused ionic and covalent bonds and thought that sodium chloride was a molecule in which sodium and chloride atoms were bonded covalently. In another study on covalent bonds, Peterson et al. (1989) found out student misconceptions about bond polarity, molecular structure, inter-molecular bonds and the octet rule. Raymond et al. (1989) also reported similar misconcepitons about bond polarity, molecular structure and polarity, intermolecular forces and the octet rule.

In her study concenrning misconceptions in chemical bonding, electronegativity and molecular structure, Nicoll (2001) found that students could not define covalent bonding correctly and confused ionic, covalent and hydrogen bonds. Coll and Taylor (2001) presented students with examples of metallic, ionic and covalent materials and asked them to identify the types of bonds in these materials. At the end of the study, they found several students' misconceptions that intermolecular covalent bonds were weak bonds, polar covalent compounds were charged, and hydrogen containing compounds like HCl were ionic.

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LITERATURE REVIEW

In a study concerning conceptual understanding of bond polarity, molecular polarity, VSEPR theory, Lewis structure and molecular structure, it was found that university students could not identify the relationship between bond polarity and molecular polarity, could not determine wheteher a molecule was polar or nonpolar, and assumed that lone pair electrons did not have effect on the molecular geometry of the molecule (Yılmaz and Morgil, 2001).

In a study on chemical bonds, Ünal et al. (2002) identified several misconceptions. Students assumed that: (a) the hydrogens in ammonia were at equal distance to each other and the bond angles were 120^o, (b) the geometry of the water molecule was linear, (c) carbondioxide molecule was polar, (d) there could not be a hydrogen bond betwen a hydrogen and a sulfur atom, (e) the chemical bond in hydrogen chloride was an ionic bond or a hydrogen bond, (f) bond length and bond angles would increase since molecules move apart from each other with increasing temperature.

In another study concerning covalent bonds, Ürek and Tarhan (2005) reported that students thought HCl was an ionic compound, nitrogen yielded covalent molecules by forming five chemical bonds, covalent bonds are formed by transfer of electrons between two nonmetals, molecules with nonpolar covalent bonds were neutral whereas those with polar covalent bonds were charged, molecules were formed via covalent bonding of identical atoms, compounds were the smallest entities made up of different atoms that bonded via ionic bonds, there shoud be double covalent bond between oxygen and hydrogen atoms in hydroxide ion. Misconceptions about chemical bonds that university students have identified in a study by Özmen (2007) include the ideas that in all covalents bonds electrons are shared equally, lone pair electrons on all atoms that are not involved in chemical bonding determine the polarity of bonds, molecular geometry is determined by repulsive forces between bonding electrons and not by nonbonding electron pairs, polarity of a molecule is due to the nonbonding electrons. Fruio and Calatayud (1996) conducted research on how university students understood molecular geometry and polarity. The students were found to have difficulty in drawing Lewis structures of molecules, determining the central atoms and distributing the unshared electrons to the atoms in the molecule. The researchers also investigated ways of eliminating the misconceptions, and concluded that three dimensional models need to be used in teaching polarity and molecular geometry.

According to Ingham and Gilbert (1991), a model is a simplified presentation of a system, which emphasizes the typical features of the system. This simplified presentation could be enriched with examples relevant to the system. Harrison and Treagust (1998) proposed that as an advanced thinking process, modelling should be included in science teaching curricula.

In general, models are used in situations where direct observations can not be made when scaling is needed even though direct observations are possible. Models could be defined as natural processes employed by scientists during the course of a study and the scientific outcomes developed as a result of these processes (Cartier, et al., 2001). From this point of view, a scientific model could be represented and processed in mind, possessing special conditions of its own. It explains issues related with a problem and sheds light onto the relevant interpretations made.

Another important feature of the scientific models is their potential to provide better explanations upon continuos use. Moreover, they can be improved, expanded and enriched through extension or combination with other models. For instance, in 1803 Dalton's atomic model could explain the conservation of mass in a chemical reaction but could not provide sufficient explanation of new information regarding the atom. In 1897 Thomson proposed the plum pudding model as a model of the atom demonstrating distribution of the negative charges in a positively charged cloud. In 1911, Rutherford made a series of experiments to test Thomson's atomic model. The results were contradictory to the plum pudding model and therefore he thought that the mass and the positive charges were located in the center of the atom, and he named this center as the nucleus. Nevertheless, Rutherford's model could not provide explanation about the movement of the electrons and the fact that they never collapsed into the nucleus. In 1913, Bohr proposed the atomic model named after his name based on the hydrogen atom and the behavior of some single electron ions. This model also fell short of explaining the behaviors of multielectron atoms. Today's modern atomic theory was proposed with contributions from Schrödinger and Heisenberg (Petrucci et al., 2005). The evolution of the atomic model is an excellent example demonstrating the adaptability and limitations of models in explaining a phenomenon, and their potential for shedding light onto new research. Because of these features, scientific models are not only desired products but also a guide for future studies. If scientific models are involved in curricula, students will have the opportunity to better learn the concepts associated with a particular discipline as well as observe how scientific knowledge is developed and evaluated (Ünal, 2006).

Researchers mentioned above have shown that students did not understand chemical bonds very well which were among the fundementals of chemistry and had some misconceptions about them. It was recommended to benefit from 3-dimensional models to teach chemical bond concepts better (Lam-Leung and Albert, 1993; Furio and Calatayud, 1996; Gupta and Brahm, 1999; Özkan, 2000; Morgil et al., 2002).

Although there are a lot of studies in which modelling is used to teach abstract science concepts, the number of studies where modelling is used as a means to overcome the misconceptions in chemical bonds is comparatively

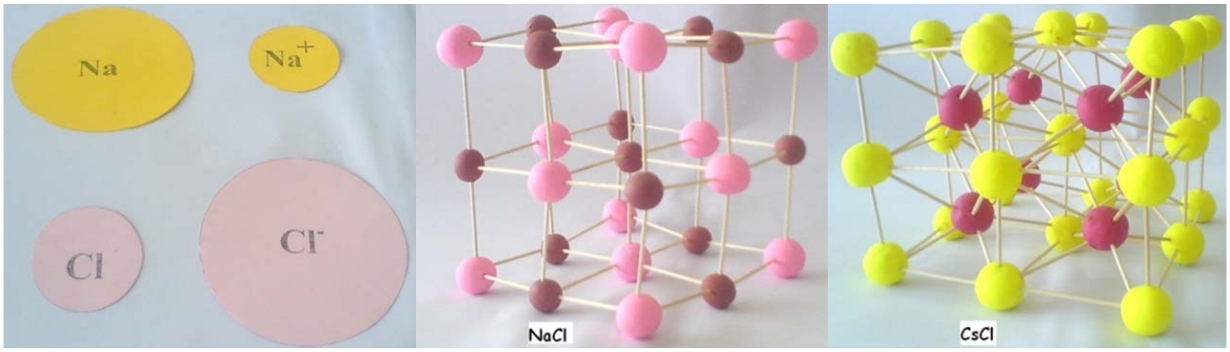


Figure 1. Na atom, Na+ ion that lost an electron, Cl atom, Cl- ion that gained an electron, and NaCl and CsCl molecules made with play dough and toohpicks.

less. The aim of this study is to reduce the misconceptions about chemical bonds in literature in the study group**.**

METHOD

Guide material

Chemical Bonds: In an introduction to chemical bonds, students' prior knowledge about the octet rule, valence electrons, ionization energy and electronegativity was assessed in the classroom environment via question-answer technique and any missing knowledge was addressed. Some of these defintions include (a) chemical bonds form due to changes in electron distrubution when atoms combine; in other words, chemical bonds are the attractive forces that hold the atoms together in molecules (Mortimer, 1997). The interaction between two atoms to form a molecule is defined as a chemical bond (Erdik and Sarıkaya, 2000). Chemcial bonds in general are known as the attractive forces that hold chemical species like atoms, ions and molecules together in chemical compounds (Sarikaya, 1997). The definition of chemical bonds was once again clarified to the students as being the electrostatic attractive force holding atoms together. It was explained that by chemical bonding, the elements all over the world form stable diatomic or polyatomic molecules through which a lower energy level is attained and this is a desired process resulting in formation of numerous compounds and molecules in our life. Some chemical bonds were explained by using models.

Ionic bond: Ionic bond forms as a result of electrostatic attraction between ions of opposite charge. The structure of ionic compounds is explained by the packing of the ions. Both intra and intermolecular bonding in ionic compounds is ionic. Metals become positively (+) charged by losing electrons while non metals gain electrons and become negatively (–) charged. The positive and negative charges formed in this way strongly attract each other. This attraction results in ionic bond formation. In compounds formed by transfer of electrons, the number of electrons lost should be equal to the number of electrons gained. NaCl, K_2S MgS, $BaCl_2$ could be given as examples of ionic compounds. For a better understanding and comprehension of the topic, students were asked to make representative Na atom, Na^+ ion that lost an electron, Cl atom and a Cl^- ion that gained an electron from color paper under the guidance of the teacher. Additionaly, they were asked to make NaCl and CsCl molecules by using play dough and toothpicks to better understand ionic bonding. The ionic bonding models built by the students are shown in Figure 1.

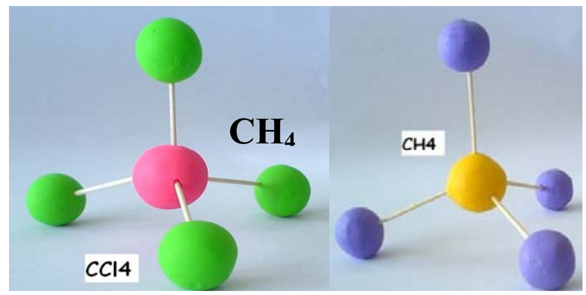


Figure 2. CCl_4 and CH_4 molecules.

Covalent bond: It is formed by sharing an electron pair between atoms. The bonding force is the attractive force between shared electrons and the positive charge in the nucleus of the atoms. The chemical bonds in H-H and Cl-Cl are fully covalent because the electrons that make up the bond are equally shared between the atoms. This type of bond is defined as nonpolar covalent bond. In some covalently bonded molecules, bond electrons are attracted more strongly by one of the atoms and as a consequence electron density shifts toward that atom. This situation is defined as either the partial ionic character or the polarity of the bond. For example, in molecules formed by different atoms like H-Cl, the electrons of the covalent bond are pulled stronger by one of the atoms and the other atom becomes relatively positively charged. This type of chemical bond is known as polar covalent bond.

a) Nonpolar covalent bond is the chemical bond formed between identical atoms. Hydrogen is a nonmetal and tends to complete its valence electrons to two to achieve the electron configuration of the nearest noble gas helium. Likewise, chloride tries to attain eight valence electrons to resemble the nearest noble gas argon. Under these circumstances, what kind of chemical bond holds the atoms together in H_2, Cl_2 molecules? Two hydrogen atoms form a chemcial bond by sharing their electrons, which is shown as H—H. As an activity, students were asked to make H_2 and Cl_2 molecules using color papers and to model the molecular geometry of H_2, CCl_4, CH_4, F_2 with play dough and toothpicks in an attempt to teach them the nonpolar covalent bond. The models made by the students are shown in Figure 2.

b) Polar covalent bond: The chemical bond between different nonmetal atoms is called polar covalent bond. In other words, in this chemical bond, electrons are not shared equally between the atoms, thus, polarization in the electron density occurs. Let us

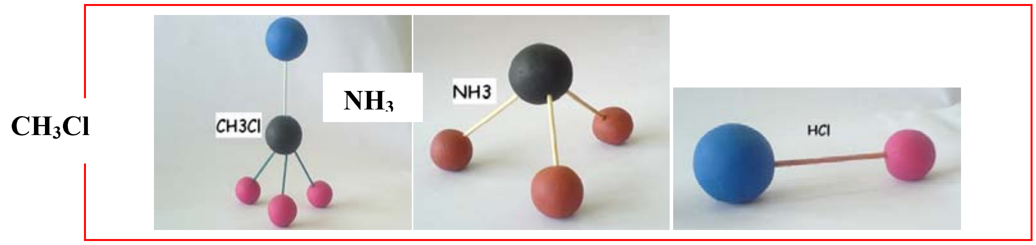


Figure 3. Molecular geometry of CH_3, NH_3, HCl molecules.

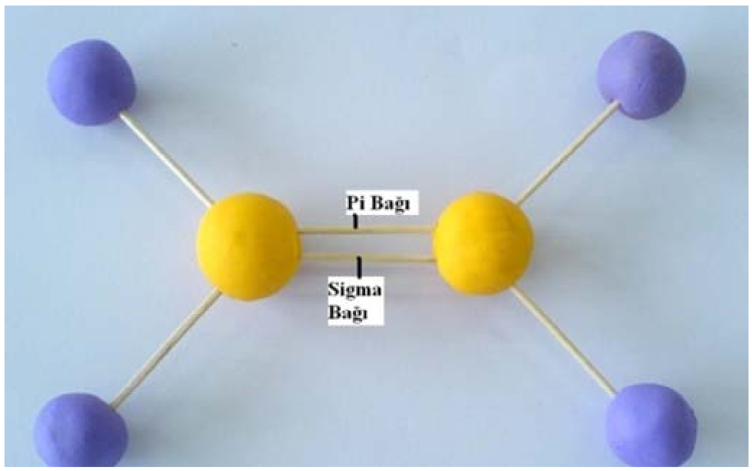


Figure 4. C_2H_4 molecule.

explain the polarity over the HCl molecule. Hydrogen and chloride form a compound by sharing their electrons. The electronegativity (tendency to gain electron) of chloride is higher than that of hydrogen, therefore electrons are relatively closer to the chloride side. As a result, chloride becomes partially negatively (-) charged whereas hydrogen becomes partially positively (+) charged. This phenomenon is known as polarization and the type of chemical bond is called covalent bond. As an activity, students were asked to build the models of HCl, CH_3Cl, NH_3 molecules with play dough and toothpicks with the purpose to better teach the polar covalent bond. The models made by the students are shown in Figure 3.

Double and triple bonds: Atoms, when needed, complete their octets by forming double or triple bonds instead of a single bond. The chemical bonds formed by sharing two or three electron pairs are called double and triple bonds. In a C_2H_4 molecule, each C atom makes two C-H bonds and one C-C bond. However, p orbital of each of the C atoms remains unhybridized that is perpendicular to the plane of sp^2 hybrid orbitals. The p orbitals overlap when two C atoms come side by side leading to an electron cloud above and below the C-C bond line to form a second C-C bond. The first C-C bond forms by head to head overlap of two sp^2 hybrid orbitals and the second C-C bond forms by sideways overlap of two p orbitals. In this case, there are two kinds of bonds in the double bond of an ethylene molecule. The bond is called sigma bond if the electron density is on the bond axis connecting the atomic nuclei. If it is above and below the bond axis, then the bond is called pi bond. In this activity, molecular geometry of the C_2H_4 and C_2H_2 molecules was modelled with play gough and toothpicks to teach the students about double and triple bonds. The C_2H_4 molecule model made by the students is shown in Figure 4.

Hydrogen bond: Nitrogen, oxygen and fluoride are the most electronegative elements; therefore the polarity of hydrogen compounds like NH_3, H_2O and HF is higher than that of other hydrogen conatining compounds of elements in the same groups. In addition, NH_3, H_2O and HF possess higher melting and boiling points than those of other hydrogen containing compounds of elements in the same groups, which is due to the fact that these molecules contain at least one nonbonding electron pair and one H atom bonded to a highly electronegative atom. Covalently bonded O, F and N atoms attract the H atom of the other molecule and the H atom forms a bridge enhancing the interaction between the two molecules. Because of the small size of the H atom, the molecules get so closer to each other that the interaction resembles a bond rather than a dipole-dipole interaction. This special bond is known as hydrogen bond. In the activity, students made H_2O molecules using color papers and play dough to learn the concept of hydrogen bonding. The H_2O molecules made by the students are shown in Figure 5.

Molecular geometry: The valence shell electron pair repulsion theory allows the determination of molecular geometries. Hybridization theory assumes symmetric distribution of valence shell electrons around the atoms in a molecule. It is assumed that the electrons are positioned as far apart as possible from each other in pairs around the surface of a sphere. All bonding and nonbonding electrons of the central atom are taken into acount in the practical application of this theory. Molecule geotmetry could be different if there are nonbonding electrons. Electron pair repulsion theory is

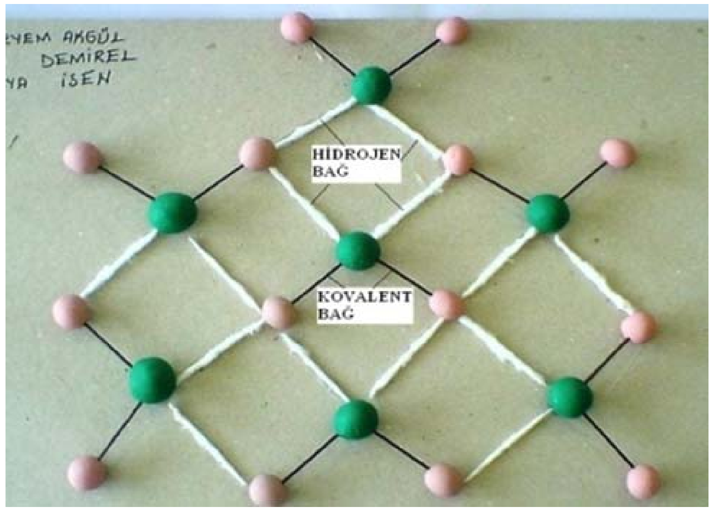


Figure 5. H_2O molecules.

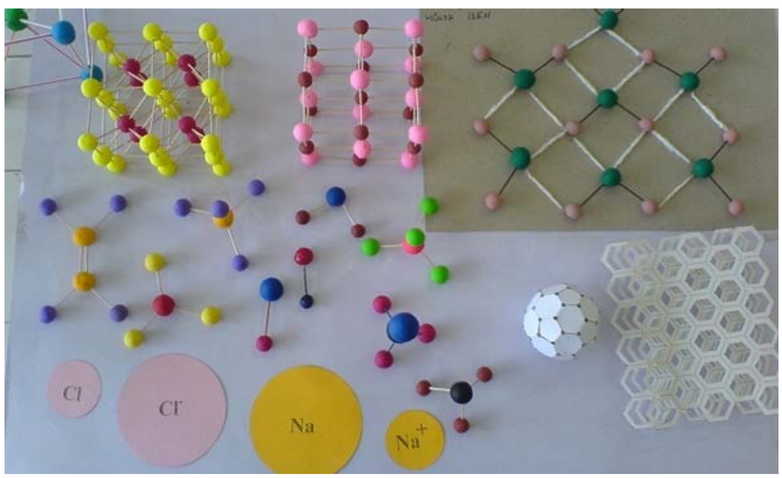


Figure 6. Some models built by students in the molecular geometry activity.

used in determination of molecular geometry of many molecules and ions.

XY type moleceules (1A and 7A, 2A and 6A, 3A and 5A): Molecules and chemical bonds are polar. Molecule geometry is linear (bond angle 180^o)

XY_2 type molecules: a) If X: 2A, Y: 7A or hydrogen; nonpolar molecules, polar chemical bonds and linear molecular geometry (bond angle 180^o). Hybridization is sp. **b)** If X: 4A, Y: 2A or 6A; nonpolar molecule, polar chemical bonds and linear molecular geometry (bond angle 180^o), sp hybridization. **c)** If X: 6A, Y: 1A or 7A; polar molecule, polar chemical bonds and bent molecular geometry (bond angle 105^o), sp^2 hybridization. In this activity, $BeCl_2$ molecule was made from play dough to teach the XY_2 molecular geometry.

XY_3 type molecules: a) If X: 3A, Y: 7A or hydrogen, nonplar molecule, polar bonds. Molecular geometry is trigonal planar (bond angle 120^o), and hybridization is sp^2 **b)** If X: 5A, Y: 7A or 1A, molecule and bonds are polar, molecular geometry is trigonal pyramidal (bond angle 107^o), hybridization is sp^3. In the activity, BeF_3 molecule was made from play dough to teach the XY_3 molecular geometry.

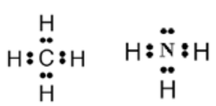
XY_4 type molecules (CH_4, SiF_4, NH_4^+, SO_4^{2-} etc.), nonpolar molecule, polar bonds, molecular geometry is tetrahedral (bond angle 109.5^o), hybridization is sp^3. In the activity, CH_4 molecule was made from play dough to teach the students XY_4 molecular geometry (Figure 6).

Data collection: In the study, a Chemical Bonds Achievement Test (CBAT) was developed which consisted of a total of 35 items including 20 multiple choice and 15 essay questions. After pilot studies were conducted with 45 prospective chemistry teachers, the test was revised. The number of multiple choice items was reduced to 14, the number of open-ended questions was reduced to 10 and the final version of the test was prepared. The reliability coefficient (Kuder-Richardson 20) of the multiple choice test was calculated to be 0.75 in the pilot study. The pilot study was conducted only as a data collection tool, not for the guide material.

The CBAT was applied to the study group twice as pre-test and post-test to measure the level of knowledge about chemical bonds. In the first part of the test, responses to essay questions were grouped into three categories as completely understood, partially understood, no undestanding/blank, and then percentages for each category were calculated (Ayas, 2002; Özmen et al., 2002). For the multiple choice part, Kuder-Richardson 20 reliability coefficient was computed as 0.72. Additionally, the validity of the CBAT was verified via the expert views of 6 faculty members at Marmara University and 8 chemistry teachers from various high schools in Istanbul.

Example question

Essay question: The central atom in CH_4 and NH_3 molecules have four electron pairs and both are sp^3 hybridized. However, the CH_4 molecule has tetrahedral geomerty whereas NH_3 has trigonal pyrimidal geometry. How would you explain this difference in molecular geometries?



Multiple choice question: Which of the following statements is/are correct?

I. Molecules with polar covalent bonds are charged whereas molecules with nonpolar covalent bonds are neutral.
II. Molecules form by covalent bonding of identical atoms, whereas compounds form by ionic bonding of different atoms.
III. HCl is an ionic compound because it dissociates into H^+ and Cl^- ions in water.
a) I ve II b) I ve III c) II ve III d) I, II ve III e) none of the above

Data analysis

Statistical analysis of data was performed using SPSS 16.0 software. In all statistical computations, a minimum of 0.05 confidence level was used. One-Sample Kolmogorov-Smirnov test was conducted to check for normal distribution of the data. Normal distribution was observed in the essay data of the pretest administration. All other data did not show normal distribution. Therefore, the nonparametric Wilcoxon signed rank test was used for statistical analysis of data. In the analysis of the answers to the essay questions, the categorization involved the following labels and scores: understanding (2 points), partial understanding (1 point) and incorrect understanding or no answer (0 point) (Özmen et al., 2002). The answers to the essay questions were evaluated based on the following criteria: Understanding; the responses using all or a great deal of existing knowledge to provide the expected answer for the question; partial understanding; responses that are acceptable but do not fully satisfy the expected answers; incorrect understanding; responses that fail to address the expected answers or responses that contain incorrect information; no answer; no responses are provided and the question is left blank. Based on this evaluation percentages were calculated. For the multiple choice questions, scoring was made as: correct answer-proper understanding (1 point), incorrect answer-incorrect understanding (0 point), no answer – no understanding (0 point). The percentages of the answers were also calculated for the multiple choice questions.

Study (treatment) period

The chemical bonding topic was covered in General Chemistry course in 4 weeks (4 h per week) by using the guide materials. Before the the study, a question – answer discussion session with all students' participation was held in order to eliminate misconceptions about chemical bonding or to fill in the missing knowledge on the topic. This preparation activity was practiced for two class hours. The physical environment and all materials were provided by the researcher during the classroom activities. Considering the students' academic achievement in general chemistry in the 2010-2011 fall semester, by using the stratified random sampling method, 10 groups were formed with 4 students in each group. The groups were informed about the guide material. During the implementation of the guide material, all activities performed by the groups were observed by the researcher and support was provided when necessary.

RESULTS

The data from the study group were tested by Kolmogorov-Smirnov test to determine if the data from the assigned groups show normal distribution.

One-Sample Kolmogorov-Smirnov test results for the test data obtained from the study group are given in Table 1. According to the results, only the essay pretest data showed normal distribution, while data from all other tests did not show normal distribution. Therefore, analysis of the data was performed via the nonparametric Wilcoxon signed rank test.

The results of the Wilcoxon signed rank test, conducted to find if there were any significant differences between multiple choice pretest and posttest scores, are summarized in Table 2. The results showed that the mean rank of the multiple choice pretest questions was 0.00 whereas it was 20.50 for the post-test. These results indicated a signficant difference between multiple choice pretest and postest scores ($z = -5.543$; $p < 0.05$) in favor of the posttest scores.

Responses to the multiple choice 14 questions in the post-test were grouped as correct, incorrect and blank, and percentages were calculated. The results are listed in Table 3.

Table 3 indicates that the percentage of correct responses varied between 70 and 90%, and that of incorrect responses was between 5 and 25%. The ratio of the students who did not respond to the questions (e.g., left blank) was between 2.5 and 15% except for questions 3, 6 and 10.

The results of Wilcoxon signed rank test, conducted to find if there were any significant differences between essay pretest and posttest scores, are summarized in Table 4. The results showed that the mean rank of the essay pretest questions was 0.00 and that it was 20.50 for the post-test. Significant differences were detected between scores of the essay pretest and posttest.

Table 1. Kolmogorov-Smirnov Z Test analysis of the distribution of data.

	Multiple choice pretest	Multiple choice posttest	Essay pretest	Essay posttest
N	40	40	40	40
Mean	2.220	11.420	4.980	16.220
Kolmogorov – Smirnov Z	3.021	1.542	1.356	2.149
p	0.000	0.017	0.0504	0.000

Statistical significance is at the 0.05 confidence level.

Table 2. Wilcoxon signed rank test results for multiple choice pretest and postest data.

Multiple choice posttest and multiple choice pretest	N	Mean rank	Sum of ranks	z	p
Negative ranks	0[a]	0.00	0.00	-5.543	0.000
Positive ranks	40[b]	20.50	820.00		
Ties	0[c]				
Total	40				

a. Multiple choice posttest < Multiple choice pretest; b. Multiple choice posttest > Multiple choice pretest; c. Multiple choice posttest = Multiple choice pretest.

Table 3. Precentages of responses to the multiple-choice questions in the posttest.

Questions	Correct (%)	Incorrect (%)	Blank (no response) (%)	Questions	Correct (%)	Incorrect (%)	Blank (no response) (%)
1	85	10	5	8	72.5	17.5	10
2	80	10	10	9	70	15	15
3	75	25	0	10	90	10	0
4	90	5	5	11	82.5	10	7.5
5	85	10	5	12	77.5	15	7.5
6	87.5	12.5	0	13	82.5	12.5	5
7	77.5	20	2.5	14	85	12.5	2.5

Table 4. Wilcoxon signed rank test results for essay pretest and postest.

Essay posttest and Essay pretest	N	Mean rank	Sum of ranks	z	p
Negative ranks	0[a]	0.00	0.00	-5.636	0.000
Positive ranks	40[b]	20.50	820.00		
Ties	0[c]				
Total	40				

a. Essay posttest < Essay pretest; b. Essay posttest > Essay pretest; c. Essay posttest = Essay pretest.

Considering the mean rank and the sum of the difference scores it becomes evident that this difference is in favor of the positive ranks, or the posttests ($z = -5.536$; $p < 0.00$).

Responses to the 10 questions in the essay post-test were categorized as full understanding, partial understanding and no understanding/blank, and percentages were calculated. The results are listed in Table 5.

Table 5 indicates that the percentage of student respsonses with full understanding varied between 70 and 80%, those with partial understanding varied between 7.5 and 20%, and the responses with no undestanding/blank

Table 5. Precentages of scores from the essay post-test which required written responses.

Questions	Full understanding(%)	Partial understanding(%)	No understanding / blank (%)	Questions	Full understanding (%)	Partial understanding (%)	No understanding / blank (%)
1	75	20	5	6	75	15	10
2	70	15	15	7	70	15	15
3	75	10	15	8	75	10	15
4	80	15	5	9	75	10	15
5	80	7.5	12.5	10	70	15	15

varied between 10 and 15%.

Ionic bond: This concept was assessed with 5 questions. Of these questions, one was essay type and the other 4 were multiple choice. Based on the responses to the essay question, the percentages for full understanding varied between 75 and 20%, and the percentage for partial understanding was 20%. The ratio for no understanding was negligible. Students were asked to define ionic bond with an example. The students' understanding at full or partial level was found satisfactory. In the multiple choice part of the test, the percentage range of correct responses to the 4 questions related with ionic bonding was between 72.5 and 90.0%.

Covalent bond: This concept was assessed with 6 questions 3 which were essay type and the other 3 were multiple choice questions. The full understanding ratio for essay questions was 70-80% and the partial understanding ratio was 15%. The students' level of understanding of the changes covalent bonds went through during a phase change as well as of the compound polarity and nonpolarity was found to be fairly high. In the second part of the test including three multiple choice questions about covalent bonds, the range of correct answers was 75.0-82.5%. The rate of correct responses regarding a possible unequal distribution of electrons in covalently bonded compounds and the fact that molecules could be polar even if intramolecular covalent bonds are polar, was fairly high.

Double and triple bonds: Three questions were asked to assess double and triple bonds knowledge. Two questions were essay type and one was multiple choice. The full understanding percentage range for the essay questions was 70-80%, and the partial understanding percentage range was 7.5-15.0%. Students' responses were found highly accurate in explaining the differences in boiling points of compounds with respect to single, double and triple bonds. The correct responses percentage to the multiple choice question was 70%.

Hydrogen bond: Hydrogen bond concept was assessed with 6 questions, 2 of which were essay type and the other 4 were multiple choice. In one of the essay questions, students were asked to predict and explain which one of acetaldehyde and acetone would dissolve in water given that both compounds included the same kinds of atoms. Full understanding and partial understanding levels for this question were 75 and 15%, respectively. In a similar question, the reason for the boiling point of ethanol being higher than that of dimethyl ether though the two molecules possessed similar moecular mass, was asked. Full undestanding rate for this question was 75% and that of partial understanding was 10%. The percentage range of the correct answers to the multiple question about this concept was between 77.5 and 90.0%.

Molecular geometry: Molecular geometry concept was assessed with 4 questions. Two of the qestions were essay type and other two questions were multiple choice. In one of essay questions, students were asked to explain why CH_4 was tetrahedral and NH_3 was trioganal pyramidal although the central atoms in both molecules had four pairs of electrons and both were sp^3 hybridized. In the other question, students were asked to explain why BF_3 had trigonal planar geometry, whereas NH_3 was trigonal pyrimidal although their central atoms were each bonded to three hydrogens. The responses provided to these questions indicated 75% full understanding, and 10% partial understanding. The range of correct answers for multiple choice questions was 80.0-82.5%.

DISCUSSION AND CONCLUSION

The subject of chemical bonds is the basis to learn many chemistry subjects, such as chemical reactions, chemical equilibrium, thermodynamics, and molecular structure. National and international studies, however, show that students describe this subject as an abstract topic and they have learning difficulties, which therefore result in misconceptions. The objective of this study was to achieve effective teaching of the concept of chemical bonds by means of models and avoid the misconceptions reported in the literature.

As reported in previous research, students often confused ionic and covalent bonds and had various misconceptions, such as thinking that sodium chloride is a molecule composed of covalently bonded sodium and chloride atoms; compounds like HCl that contain hydrogen are ionic and involve one of the hydrogen bond or ionic bond (Butts and Smith, 1987; Nicoll 2001; Coll and Taylor, 2001; Yılmaz and Morgil, 2001; Ürek and Tarhan, 2005). On the other hand, the results of this study demonstrated that these misconceptions were at a negligible level among the participating students. Students were able to differentiate between compounds containing ionic and covalent bonds very accurately.

In addition, studies on the understanding of chemical bonds have found that students were unable to define covalent bond and had misconceptions, including the views that intermolecular covalent bond was a weak bond and that polar covalent compounds were charged. Also, studies suggested that many students had difficulties in differentiating polar and nonpolar molecules, and thought that the chemical bond in the HCl molecule is an ionic or a hydrogen bond; covalent bond forms between two nonmetals by transfer of electrons; electrons are equally shared in all covalent bonds, and covalent bonds would form when atoms have similar electronegativities (Nicoll, 2001; Coll and Taylor, 2001; Ünal et al., 2002; Ürek and Tarhan, 2005; Özmen, 2007). The students holding these misconceptions in this study were very rare and the occurrences were even negligible. About 80% of the students have accurately identified covalent bond containing compounds and have indicated that no changes occured in covalent bonds during phase changes. These results demonstrated that the students understood these concepts well.

In previous studies, it was found that students drew the structure of H_2O molecule as linear; thought that the HCl acid contained hydrogen bonds and misunderstood hydrogen bonds (Ünal et al., 2002; Nicoll, 2001). Though seen in past studies, these and similar misconceptions were found to be negligible among the students who participated in this study. In this study, the students were able to explain accurately the reason why ethanol had higher boiling point than dimethyl ether despite both having the same molecular mass. While in general the boiling point increased with increasing molecular mass for acids of halogens in the order of HF, HCl, HBr, HI, the students explained the reason for the boiling point of HF being higher than that of HCl. When they were asked about the changes they expected to happen when water boiled, they responded that the disorder of water molecules would increase and the molecules would separate from each other as the intermolecular hydrogen bonds broke.

In the literature, a number of misconceptions were found about molecular geometry including the ideas that the nonbonding electron pairs around the central atom had no effect on molecular geometry; molecular geometry was only due to the repulsion among the bonding electron pairs; bond angles in ammonia were 120^o and the hydrogens were at equal distance to each other; and water had a linear geometry (Yılmaz and Morgil, 2001; Özmen, 2007). In this study, as large ratio as 82.5% of the students has shown correct understanding of molecular geometry as being determined by both nonbonding and bonding electron pairs. About 85% of the students explained correctly why methane had tetrahedral and ammonia had trigonal pyramidal molecular geometry, despite the fact that both methane and ammonia molecules included four electron pairs around the central atom and both involved sp3 hybridization. These results demonstrated that the molecular geometry concept was well understood among the students. Consistently, researchers have concluded that the use of three dimensional models was necessary in teaching molecular geometry (Fruio and Calatayud, 1996).

In the light of these results, the understanding of chemical bonding concepts was found to be at a high level when active learning was encouraged by building and using models. Students expressed that in this learning environment they found opportunity to immediatley ask questions about the points they did not understand and that learning by using models was more enjoyable. Because of the abstract nature of the chemical bonding subject models were effective in teaching the concepts in a more tangible manner and in enhancing better understansding.

As indicated in the literature review, teaching abstract subjects is difficult and students have conceptual understanding problems throughout the teaching process. For that reason, visual materials, computer animations, posters and models that will stimulate students' minds are benefited when teaching abstract concepts since these materials induce more senses. Therefore, students do not forget the activities which they participate in actively and succesful learning environment is accomplished (Friedler and Tamir, 1990; Lam-Leung and Albert, 1993; Gupta and Brahm, 1999; Özkan, 2000; Harrison and Treagust, 2000; Morgil et al, 2002). In our study, it was found that students could understand the topic better by constructing models.

Active and student-centered approaches entail teaching science concepts interactively with models and materials. In this manner, we hope that constructing models that are appropriate to the subject will increase academic achievement especially those that are related to science. This study will contribute to the fields of chemistry and science education.

Conflict of Interests

The author has not declared any conflict of interests.

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