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ORIGINAL ARTICLE

Scientific Argumentation in Teaching Hydrogen Bonding

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ABSTRACT

This study was conducted to determine the differences in the conceptual understanding of 52 Turkish students who were taught with a scientific argumentation approach in grade 12 chemistry. The concept test was administered to the participants as a pre-test and post-test, and it contained two questions. The first had two sub-questions had two steps. The second had six sub-questions. The researcher of the current study, who was well-versed in chemistry education, and a chemistry teacher, expressed their views regarding the content validity of the concept test. The criteria scales and scoring rubrics were prepared by the researcher to evaluate the test in terms of a conceptual understanding of hydrogen bonding. This study, which thoroughly aims at learning the effects of scaffolding with argumentation, applied mixed-methods research to reveal students' understanding of hydrogen forces and to determine schemas by drawing. In quantitative analysis, the mean, median, and standard deviation values of the data collected from the students were considered. In qualitative analysis, the drawings and explanations of the students on the concept tests applied before and after the education were discussed. According to the results of the concept tests, improvement in the conceptual understanding of the students before and after the argumentation-based teaching could be observed; however, half of the students still evidently had a rote understanding. In conclusion, the scientific-argumentation-based teaching approach was effective in developing their conceptual understanding. Recommendations are made as a result of this study.

KEY WORDS: conceptual understanding; hydrogen bonding; high school; scientific argumentation

INTRODUCTION

Science education primarily aims to remove the understanding difficulties students face in the scientific field. Numerous studies have revealed that students have difficulties in understanding chemistry, particularly the micro level of most chemistry concepts (Haigh et al., 2011). Students tend to memorize various facts about chemistry instead of understanding the chemical principles connecting basic concepts (Canpolat, 2002; Şekerci, 2015). Nakhleh (1992) stated that even if students work hard, some fail to understand chemistry concepts as they incorrectly structure basic chemistry concepts in their minds. Teaching on a conceptual level is crucial for realizing a sound understanding related to chemistry subjects and concepts. In a conceptual understanding, the existing knowledge of the students has a significant effect on the knowledge to be acquired later, and knowledge is regarded as grasped if it can be applied to new situations. Thus, students' preconcepts and preexisting knowledge structures are substantial for meaningful learning in concept teaching (İnan and İnan, 2015).

While learning chemistry, building connections among its macroscopic structures representing the holistic vision of substances, the formulas representing its symbolic level, the particles composing the holistic structure, and the microscopic level representing the relations between particles is essential. One of them is the subject of chemical bonds. The subject of chemical bonds is one of the abstract topics of chemistry, and it is vital for the understanding of many chemical concepts in secondary education and at the university level (Hurst, 2002; Nahum et al., 2006; Nahum et al., 2004; Yayon et al., 2012). Bonding is a central concept in chemistry teaching; therefore, a thorough understanding of it is essential for understanding almost every other topic in chemistry, such as carbon compounds, proteins, polymers, acids and bases, chemical energy, and thermodynamics (Hurst, 2002).

The concept of chemical bond is considered a difficult topic by both teachers and students, and correspondingly some misconceptions may materialize (Awan et al., 2012; Birk and Kurtz, 1999; Col and Taylor, 2002; Schmidt et al., 2009; Peterson et al., 1989; Taber, 1998). Some of the misconceptions are as follows: (1) Covalent bonds are formed by one electron alone or through electron transfer; (2) intramolecular bonding exists in ionic compounds; (3) intramolecular bonds are broken during phase changes; and (4) intermolecular forces are absent in polar substances (Col and Taylor, 2002). Many of these misconceptions stem from the oversimplified patterns in textbooks, traditional teaching methods, and the ways to assess student achievement. Furthermore, differences in the basic definitions of chemistry concepts by scientists and the inappropriateness of the patterns used to explain the topic are other possible reasons for these misconceptions (Nahum et al., 2010).

According to Chittleborough and Treagust (2008), teachers utilize symbolic representations and shift between the observable or macroscopic and abstract or symbolic levels without paying sufficient attention to how these relate to the micro level. The subject of chemical bonds is impossible to learn with the understanding of only the macroscopic level and symbolic representations of substances and without the development of a cognitive pattern comprising the particular structure of substances and the forces holding these particles together (Tan and Treagust, 1999). The concepts related to intramolecular bonds and intermolecular forces, such as covalent bonds, dipole–dipole repulsion, and hydrogen bonding, are abstract, and students must comprehend on not only the symbolic and macro levels but also the micro level to attain meaningful understanding. They need to know about the physical concepts and laws associated with the bonding concept, such as orbital overlapping, electronegativity, electron repulsions, polarity, and core charge. Moreover, learners need to make predictions and interpret the data regarding the physical and chemical properties of substances.

The inflexible traditional approach has limitations; in many textbooks, covalent, and ionic bonds are identified as "real and strong" chemical bonds, whereas hydrogen and Van der Waals bonds are considered "forces" (Taber, 1998). In reality, this differentiation is rather rigid or misleading. Here, two related oversimplifications are present: One of them is the classification of hydrogen bonds as strictly intermolecular, although they are often intramolecular (in proteins for instance), and the other one is the discussion of such bonds only when fluorine (F), oxygen (O), or nitrogen (N) atoms are involved, although hydrogen bonds — whether weaker or nonconventional — may occur with other atoms or groups as well (Naaman and Vager, 1999).

Henderleiter et al. (2001) affirmed that hydrogen bonding is a basic chemical principle that has applications in all areas of chemistry. They reported that students confuse hydrogen bonding with a covalent bonding that exists between hydrogen and some other atoms and think that intramolecular hydrogen bonding results in the formation of new covalent bonds. In addition, they commented that these results validate that even if the student is in the 2nd year of college, they still have the same misconceptions as less experienced students.

According to Taber (2002), teachers must find the most appropriate level of simplification: Simplifying sufficiently to meet the current goals of learners but not oversimplifying to blight their future needs. Over the years, the traditional pedagogical approach has become increasingly simplistic and has taken over clear-cut definitions to aid student learning. Unluckily, the mentioned superficial teaching results in rote learning. Students generally do not apprehend these concepts but acquire many misconceptions, and their pseudo-conceptions also reflect this consequence (Vinner, 1997).

Taber (2002) suggested a framework for building an understanding of the bonding concept with building blocks (forming a basis) in a manner of not causing oversimplification, similar to solid foundations necessary for the construction of a building, instead of presenting several concepts independent of one another. In the structure they constructed, each layer forms a basis for the next one just like a pyramid. According to Taber (2002), development of a new understanding is afforded through the knowledge the students already have. They introduced the structure they constructed with the elemental principles of an isolated atom (Stage 1), followed by a discussion of general principles regarding the chemical bond between two atoms (STAGE 2). At this stage, according to Luckin (1998), support should be provided to students to organize their existing knowledge. Here, the teacher may help them organize their knowledge and assist in highlighting their prior knowledge with his/her questions. At Stage 3, the general principles are employed to present the divergent traditional categories of chemical bonding as extreme cases of various continuum scales. At Stage 4, wherein a new understanding is formed, students construct their sound understanding about diverse molecular structures, and at the last stage (Stage 5), the properties of bonds are discussed. According to Taber (2002), students can be provided with temporary support to organize a new understanding when considered necessary.

In the past two decades, various approaches have been produced to scaffold students' learning. Students have been provided with scaffolding in the form of paper-and-pencil tools, technological resources, peer support, or teacher-led discussions. Distinct types of scaffolding, such as diversified activities according to their difficulty levels or content of the task (Luckin, 1998), have also been presented. Tytler (2007) claimed that teachers have an essential role in assisting science students by promoting discourse communities, encouraging exploratory activities, and providing explanatory opportunities in the construction of knowledge. Vygotsky believed that learning first takes place on the social or interindividual level with an adult or a more high-capacity peer and underlined that the role of social interactions was vital to cognitive development (Prain et al., 2009). Karasavvidis (2002) advocated that scientific argumentation requires the necessity of the multimodel communication essential to science learning to construct understanding by socially employing multimodel texts and models in which linguistic, numerical, and tabular charts are utilized to present, express, and explain the scientific findings. They not only help students construct their knowledge effectively by promoting participation in various learning activities or the use of different teaching materials but also provide support in the form of modeling, emphasizing the critical characteristics of the task and providing tips and questions that might help the learners reflect (Taber, 2002).

In this respect, argumentation practices for supporting chemical understanding and providing indications and evidence for the emergent characteristic of chemical entities, their properties, and interactions were suggested by researchers (Erduran and Jiménez-Aleixandre, 2007, Tümay, 2015). Argumentation is the process of arriving at conclusions by reasonably evaluating data in a social environment through formal or informal ways to assess alternative perspectives

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and solutions (Driver et al., 2000). Argumentation is an individual activity because it involves processes, such as thinking and criticizing, and is also a social activity as it occurs within a group or contains justification (American Association for the Advancement of Science, 1993). Making claims, using data to support these claims, warranting the claims with scientific evidence, and justifying or changing claims and warrants are the key factors students employ in the argumentative process. Through this, students learn the scientific concepts and participate in the authentic practices of science (Osborne, 2001). In argumentation, as students present their own opinions, their misconceptions are easily identified, and their understanding becomes more meaningful and deeper. Accordingly, science educators should advocate the use of argumentation. For instance, according to Driver et al. (2000), the employment of discursive activities in science lessons is efficient for constructing scientific knowledge and conceptual development. Moreover, Osborne (2001) suggested the use of argument for deeper and more meaningful learning about science for students.

A new science teaching approach wherein argumentation is placed in science classroom practices aims to convince rather than force students to acknowledge scientific views. In this activity, students present and defend their views through argumentation. Disagreements among students often exist at this time. The literature about conceptual change pedagogy suggests that this is the time for teachers to reveal scientific concepts. Students do not easily give up their own views. Showing students that their ideas bring about self-contradictions is a useful strategy to cite unacceptable ideas. During argumentation, students should be open-minded, endeavor to understand the views of others, and be ready to change their own ideas. This approach is a dynamic process that should be organized by teachers in terms of breaking down old opinions and building new and scientifically corrects ones (Nussbaum et al., 2008).

In fact, knowledge should be developed through social negotiation and the evaluation of the viability of the proposed ideas (Cross et al., 2008). Therefore, in classes, teachers should not aim to transmit the knowledge but aim to engage students in critical thinking about scientific concepts, reasoning through supporting their claims using scientific evidence, and justifying their claims with appropriate explanations. The educational implementation that supports the conceptual changes of students and ensures these features is based on scientific argumentation (Cross et al., 2008; Şekerci and Canpolat, 2014). According to Schmidt et al. (2009), the understanding of intermolecular forces for the upper secondary school students is inadequate, and teaching should be changed.

The current classroom study was conducted to explore the effects of the instruction that focused on scaffolding by argumentation to increase the comprehension of the students and their ability to employ and communicate with representations about hydrogen bonding in chemistry. The activities and instructional resources in this study were employed to help them learn how to relate to concepts and phenomena and learn how to select, represent, and explain the experimental data and physical properties of substances that contain hydrogen bonding. Therefore, the research question was "What is the effect of the instruction that focused on scaffolding through argumentation on the understanding of students regarding hydrogen bonding?" The current research aimed to ascertain the effect of argumentation on the students' level of recognizing hydrogen bonds between different molecules and establishing and explaining the physical properties of molecules having hydrogen bonds conceptually in the micro level using data about electronegativity and the standard enthalpy of vaporization.

METHODOLOGY

The study was conducted with 52 students studying in grade 12 (students aged 17) in a public high school in the province of Çankırı, Turkey during the 2015–2016 academic year. This study was conducted with the voluntary participation of the students. The study duration was 4 weeks, and the students were first given the concept test about hydrogen bonding. The test involved two questions, and the first question had two subheadings. In the first part of this question, the students were required to draw the form and structure of a hydrogen bond. In the second part, six molecules were given, and they were once again required to draw and discuss whether these molecules could form a hydrogen bond between one another and with water. The second question of the test included six items. In each item, two molecules and the comparisons of these molecules in terms of boiling points and solubility were given. They were asked to discuss the reasons underlying the differences between the boiling points and the solubility of the molecules. The content validity of the concept test was checked by a chemistry expert and a chemistry teacher, and all the questions were piloted to 24 students studying in grade 12. As a result of the pilot scheme, no confusion occurred related to the complexity of the questions, and the formulas of the molecules were given. The evaluation criteria were defined by the teacher and the researcher. They separately evaluated the answers, and the total points were calculated considering the point average of each question the students answered. Table 1 presents the evaluation criteria and points for each question. The scoring system in the table shows that moving through higher points, the students shifted their focus from the macroscopic aspects of a fact or a phenomenon and its drawing to providing molecular explanations using the correct symbolic levels of drawing and accurately interpreting data. The upper points assigned to the student responses depended on the degree of the drawings and explanations on the molecular level. The maximum score of the concept test was 44.

The chemistry classes of the research classroom were taught by the same teacher since grade 9 by applying concept teaching, in-class discussions, question–answer, and instructional methods. The study was designed in a way to include hydrogen bonds. The topics within the context validate that strong and weak interactions, including hydrogen bonding and fall under the grade 12 curriculum. The study, which aimed at learning the effects of scaffolding with argumentation, applied mixed-methods research to reveal the students' understanding of hydrogen forces and determine images by drawing. In quantitative analysis, the mean, median, and standard deviation values of the students were calculated and in qualitative analysis, the drawings and explanations of the students in the concept tests applied before and after the education were discussed.

The concept test was applied at the beginning of the study as a pretest. In the beginning class of the study, the students were given the part of the periodic table including 20 elements. In the table, the electronegativity and atomic number were presented. The table also contained data about the electron configurations, nuclear charges, and the effective nuclear charges of some elements. Some of them were left blank, and the students were required to fill them in. In this activity, the students initially studied by themselves, and then, the activity were conducted as a classroom discourse. The table is given in Appendix 1. Classroom discourse was conducted regarding the interpretation of the data about these atoms. Five argumentation activities were performed in seven chemistry class hours in the two groups. Two of them are given in Appendix 2.

Quantitative Analysis

This section involves a general assessment where in the quantitative analyses of the student responses are conducted: Mean (*M*) = 10.23, median (*Mdn*) = 12.50, standard deviation (*SD*) = 8.66, minimum = 0.00, and maximum = 26.00. Four groups with equal number of students were formed after ordering student scores from the pretest in an ascending order. If more than one student had the same score at the distinction point, then they were positioned at the group that had a greater number of students with equal scores. Collaboration in group argumentation did not enhance student performance and did not assert substantial effects while forming strong arguments when all the group members were going through the same difficulties (Heng et al., 2014). Hence, the students in the first quartile, below the median, and the ones in the third quartile, above the median, were combined into a group. Those in the second quartile, below the median, and the ones in the fourth quartile, above the median, were combined into another group. Table 2 presents the percentage values of the scores from the concept pre-test.

The maximum score in the first quartile was found to be 2.00, and the maximum score in the second quartile was found to be 12.00. Given that the frequency of the students obtaining two points from the test was seven and that only two students fell within the second quartile, the two students were placed in the second quartile. Likewise, the frequency of the students obtaining 17 points was three, and only one student was placed in the third quartile. This student was placed into the third quartile group of the students who had 17 points. The students in the second and fourth quartiles were combined into a group (Q_{2-4}), and the ones in the first and third quartiles were combined into another group (Q_{1-3}). Finally, 27 students were appointed to the Q_{2-4} group and 25 students were appointed to the Q_{1-3} group. The scores of the students in the Q_{1-3} group (*M* = 8.28, *SD* = 7.42, minimum = 0.00, and maximum = 17) were lower than those of the students in the Q_{2-4} group (*M* = 12.03, *SD* = 9.44, minimum = 2.00, and maximum = 26.00).

At the end of the teaching, an increase was observed in the points of all the students. The score increase of the students in the Q_{2-4} group was higher than that of the students in the Q_{1-3} group. The scores of the students in the Q_{1-3} group during the posttests (*M* = 20.80, *SD* = 10.57, minimum = 3.00, and maximum = 39) were lower than those of the students in the Q_{2-4} group (*M* = 26.52, *SD* = 10.05, minimum = 11, and maximum = 42).

Table 1: Evaluation criteria and scores of the concept test

Description	Score
Employing an incorrect molecule or atom pattern; presenting as an intramolecular bond; displaying the interaction between molecules in a line form as in intramolecular bonds; incorrect identification of partially positive or negative atoms in molecules; and imperfect, incorrect, or irrelevant identification of the interaction type	0
Identifying the type of bond correctly; presenting as an interaction between molecules; using a formal representation with a focus only on their syntax instead of their meaning; and focusing on macroscopic properties and not making any explanations based on the underlying causes of interactions between particles	1
Identifying the partially positive and negative atoms in the molecule correctly; and using a formal symbol system (indicating the partially positive and negative poles and the direction of the electron density with an arrow) to represent underlying processes based on syntactic rules and meaning regarding the phenomena	2
Showing the positions of bonds; placing them between adjacent atoms; specifying its underlying causes in a more sophisticated and detailed way; and focusing more on the molecular features of drawings to interpret differences between physical properties	3

Qualitative Findings

Question 1 focused on the definition of hydrogen bonding, while Question 2 focused on the comparison of the boiling points of substances and the explanation for the relevant reasons. Question 2 that focused on a particular phenomenon or concept required the students to interpret or explain using the representations and the data.

Table 2: Concept pre-test percentage values

Statistics	Percentiles						
	5	10	25	50	75	90	95
Weighted average (Definition 1)							
Concept	0.00	0.00	2.00	12.00	17.00	23.00	26.00
Tukey's hinges							
Concept			2.00	12.00	17.00		

Analysis of Question 1A

Q1.A. Explain the forming of hydrogen bond schematically.

For this question, 31 students in the pretest and eight students in the posttest gave inaccurate responses. The majority of the students who gave the wrong answer in the pretest and all the students who gave the wrong answer in the post-test depicted the hydrogen bond as a covalent bond in their drawing. Forty percent of these students defined the bond between fluorine, oxygen, and nitrogen atoms in the molecule and hydrogen as a hydrogen bond and employed ammonia and water molecules in their models. In the pretests, three students employed the example of hydrogen molecules to define the methane molecule; four students used the example of hydrogen molecules to define a hydrogen bond. Moreover, four students showed this bond between the hydrogen of two water molecules in the pretests. These students demonstrated hydrogen bonds with dots to refer to the attraction force between molecules in their drawings. One student did not answer this question in the pretests, whereas all students answered the question in the posttests.

Eighteen students in the pretests and 15 students in the posttests employed some symbolic representations but did not go beyond the surface level of the representation in their explanations. They tried to define the bond over water, hydrogen fluoride, and ammonia molecules and defined the bond as weak interactions occurring intermolecule between fluoride, oxygen, and nitrogen atoms and hydrogen atom. Nevertheless, they did not mention the partially positive or negative concepts. They focused only on their surface features without explanations, and they did not explain what this meant or relate this characteristic to an explanation regarding the ability to form hydrogen bonds.

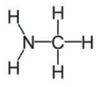
Three students in the pre-test and 17 students in the posttests provided some explanations based on the macroscopic level. Some of them employed electronegativity and bond energy values in their explanations; they successfully recalled the values, and the representations they drew were scientifically correct. They defined hydrogen bond as the attraction force between hydrogen, fluoride, and nitrogen atoms, which are quite electronegative, and used coding with an arrow to show polarity and electronegativity for the molecules they drew or coded through partially negative or positive symbols.

Six students provided some explanations based on the macroscopic and submicroscopic levels in the posttests. They connected the macroscopic and submicroscopic levels, and the representations generated were scientifically accurate. Furthermore, they correctly utilized the experimental data and were able to recall them for their explanations in the activities. Moreover, the students defined hydrogen bond by relating it to several factors, such as size, nuclear charge, effective nuclear charge, and electron density, and they employed a ‘bottom-up’ approach, moving from atomic to bond properties. The drawings of three students before and after the application are presented below. The analysis of the drawings affirmed that Student 1 defined hydrogen bond as an intramolecular bond and that Student 2 showed hydrogen bond as a bond formed between the hydrogens of two water molecules. Both students used partially negative and partially positive symbols to indicate polarity in their representations after the argumentation. In contrast, their explanations were based on only electronegativity difference factors. Student 3 defined hydrogen bond in the pretest as the bond that hydrogen established with an atom of nitrogen, oxygen, or fluorine in a separate molecule (—FH, —NH, or —OH). In the post-tests, they defined partially positive and negative atoms, showed the hydrogen bond with dots between two molecules, and exhibited electron density with an arrow directed toward oxygen atoms. A hydrogen atom acts as a bridge linking a highly electronegative atom of to which it is bonded and a lone pair of electrons of the electronegative oxygen atom of another molecule in his/her hydrogen bond model. This student stated that the nucleus of oxygen contained eight protons and two shells; that two electrons were present in the inner shell and six electrons were present in the outer shell; that although the diameter of oxygen was greater than that of hydrogen, the electrons of the first shell would shield the attraction of the electron in the second shell by the nuclear charge of oxygen, and therefore, the effective nuclear charge would be six, not eight; that hydrogen did not have any shielding effect onto the electrons in the outer shell; that the effective nuclear charge of hydrogen was one, and therefore, the electronegativity difference would be significant and the polarization would be high; that the electron density would center on the oxygen side; and that there were four electron pairs in the outer shell of the oxygen atom in water molecules and these electrons are organized into two “non-bonding” pairs, and therefore, the bond is polar and a strong hydrogen bond would be established between two water molecules. Examples of the drawings of four students before and after the application are presented below (Figure 1).

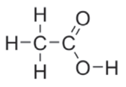
Analysis of Question 1B

In part B of the first question, the students were given six molecules and were required to discuss whether these molecules could form hydrogen bonds between one another and with water. The question was as follows:

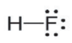
Q1.B. Which of the below compounds can form a hydrogen bond (a) between one another in liquid form and (b) with water? Schematically explain and demonstrate the reason.



Methylamine



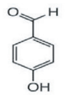
Ethanoic acid



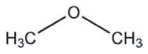
Hydrogen fluoride

H-H

Hydrogen



4-Hydroxybenzaldehyde



Methoxymethane

In parts a and b of the question, the number of the students defining the hydrogen bond as that which hydrogen fluoride molecules established between one another and with water, indicating the partially negative and positive changes, in the pretests was higher than that who defined the hydrogen bond with other molecules (19 students). Thirteen students in the pretests established the hydrogen bonds as that which HF formed with water. Forty students in the posttests drew the hydrogen bond of the molecules of HF between one another, and 42 students correctly drew the hydrogen bonds formed with water. Seventeen students among these indicated an intermolecular attraction between a partially charged hydrogen in one molecule and a partially negatively charged nitrogen, oxygen, and fluorine in a nearby molecule.

In the pretests, 17 students indicated that no hydrogen bond could be formed between hydrogen molecules and fourteen students indicated that no hydrogen bond could be established between hydrogen molecules and water. All the students gave a correct answer in the posttest. In addition, 13 students detailed their answers through electronegativity and polarity concepts in the pretests.

Fifteen students identified the hydrogen bond between the amine groups, and 11 students correctly identified the hydrogen bond these molecules established with water. The common mistake about these molecules in the pretests was that the hydrogen bond was established between hydrogens in an amine molecule and oxygen in a water molecule. In the posttests, 41 students correctly demonstrated the hydrogen bond that these molecules established between one another and with water. Thirteen students also demonstrated the polarity of the bonds and the molecules in their drawings.

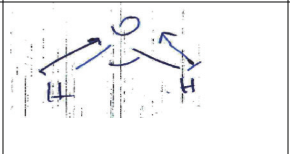
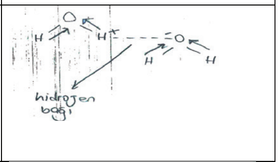
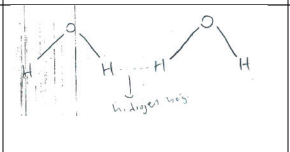
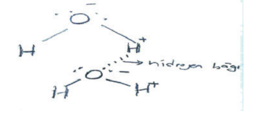
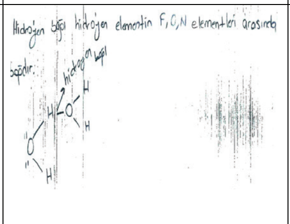
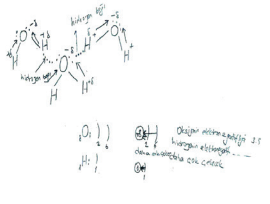
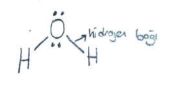
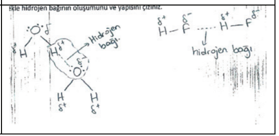
Student	Pre-test	Post-test
Student 1		
Student 2		
Student 3		
Student 4		

Figure 1: Drawing samples from the pretests and posttests for Question 1a

In the pretests, 19 students stated that no hydrogen bond was established between ether molecules, and eight students asserted that no hydrogen bond was established between ether and water molecules. The majority of these students stated that it was a polar molecule and that it was more volatile than alcohol as it contained no hydrogen bond. Eleven students did not answer this question. In the pretests, 19 students correctly drew the hydrogen bond between ether molecules on the macro level, and thirteen students correctly drew the hydrogen bond that ether molecules established with water. In the posttests, 41 students correctly identified the hydrogen bond established between ether molecules, and 37 students correctly identified the hydrogen bond between ether and water molecules. In the posttests, nine students correctly identified partially positively and negatively charged atoms between ether and water molecules and demonstrated the electron density in their drawings.

The analysis of the answers indicated that the students had difficulty in answering questions related to ethanolic acid and 4-hydroxybenzaldehyde molecules in the pretests and posttests. The number of students who showed the hydrogen bond between ethanolic acid within only the OH group was large. They commonly fell into errors regarding the identification of the bond that this molecule established with water: 19 students stated that a hydrogen bond could be established between the hydrogen atom at the –OH side in ethanolic acid molecules and the oxygen atom in a water molecule. Thirteen students in the pretests and 40 students in the posttests correctly identified the hydrogen bond between ethanolic acid molecules. Moreover, 11 students in the pretests and 39 students in the posttests correctly defined the hydrogen bond between ethanolic acid and water molecules. In the posttests, 13 students correctly defined the partially negatively and positively charged atoms and demonstrated the intermolecular interaction with lines. Thirteen students correctly identified the hydrogen bond between 4-hydroxybenzaldehyde molecules in the pretests, while this number increases to 39 in the posttests. Nine students correctly identified the hydrogen bond between the

Table 3: Question 2 in the concept test

Q2) Explain the following facts and observations:

a. The vaporization heat of ammonia (NH_3; $\Delta Hvap = 23.3$ kJ mol^{-1}) is greater than that of phosphine (PH_3; $\Delta Hvap = 14.6$kJ mol^{-1}).
b. Water (H_2O) is a liquid at room temperature, while hydrogen sulfide (H_2S) is a gas.
c. The normal boiling point of hydrogen fluoride (HF) is higher than that of hydrogen chloride (HCl), and HF is a weak acid, whereas HCl is a strong acid.
d. Ethanol (CH_3CH_2OH) dissolves better in water at room temperature than ethanol (CH_3CHO).
e. The normal boiling point of methanol (CH_3OH; 64.7 °C) is greater than that of methylamine ($CH_3NH_{2;}$ KN = −6 °C).
f. Ethyleenglycol ($HOCH_2CH_2OH$) dissolves better in water at room temperature than ethanol (CH_3CH_2OH)

Science Education International
32(3), 197-208
https://doi.org/10.33828/sei.v32.i3.3

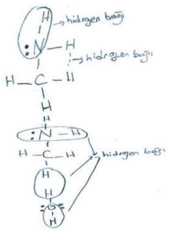
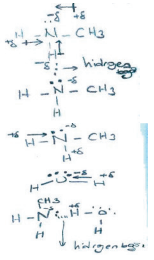
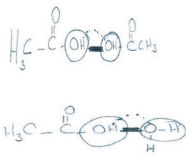
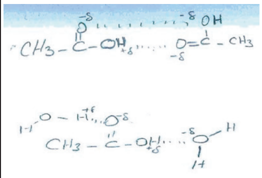
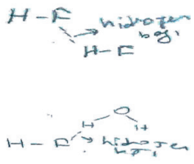
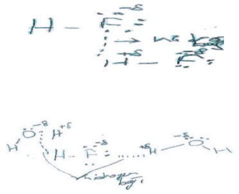
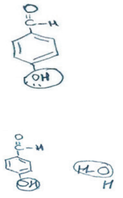
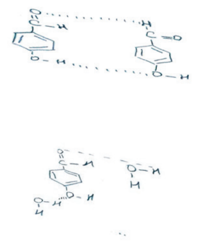
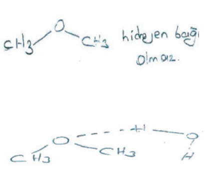
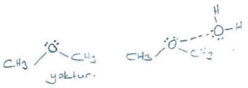
Molecule	Pre-test	Post-test
Methylamine	 Student 3	
Ethanolic acid	 Student 5	
Hydrogen fluoride	 Student 6	
4-Hydroxybenzaldehyde	 Student 7	
Methoxymethane	 Student 1	

Figure 2: Sample drawings for Question 1b

molecules and water molecules in the pretests, while this number increases to 38 in the posttests. Figure 2 presents the sample drawings and explanations of the students.

Analysis of Question 2

Six statements were provided to identify the understanding levels of the students regarding the effect of the hydrogen bond on the physical features of molecules. In each statement, data were presented about the physical features of two different molecules, and the students were required to explain their reasons. Table 3 presents the questions.

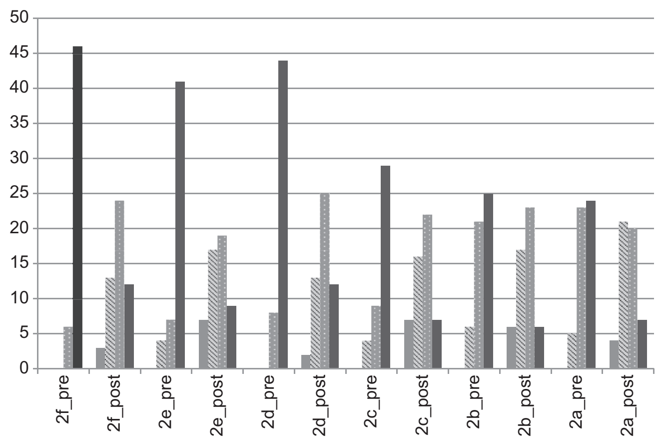


Figure 3: Frequency of students' points for Question 2

Figure 3 depicts the results of the Question 2. When the graph is analyzed, an improvement in the conceptual understanding of students before and after the application could be observed, yet some students still had some misconceptions after the application, and the ones with rote understanding still comprised approximately 45–50% of the students.

The fact that students presented their warrants for their statements in a, b, c, and d as "having stronger hydrogen bond" indicated that they understood the establishment of hydrogen bonds between molecules. The students indicating that hydrogen bonds are strong bonds (no mention about which interaction she/he compared it with) identified hydrogen bonds either between hydrogen atoms in the molecule or between carbon–hydrogen atoms. In the pretests, irrelevant answers, such as efficient order, "acid > alcohol > aldehyde' in d, e, and f, were encountered. In the pretests, 13 students presented their warrants, mentioning that 'its density is greater" for a, b, and c; however, only four students detailed it, mentioning that the "volume increases from top to bottom in the periodic table and that is why density decreases." In the posttests, four students explained the same substances with density variables. Two students explained their answers as "electron sequence depends on the density of atom as electrons disperse into a smaller diameter." Another misconception some students had was the establishment of a hydrogen bond between the hydrogen (H) atom attached to carbon (C) in organic molecules and oxygen in other molecules.

When the pretest and posttest scores were analyzed in Question 2, some students had difficulty in explaining the conditions in substances d, e, and f. Approximately 45% of the students in the pretests could more easily identify the intermolecular interactions to compare the boiling points or the solubility of inorganic molecules on the basis of the electronegativity difference of atoms in the molecule even if they did not know the underlying reason. Majority of the students in the study easily and correctly demonstrated the hydrogen bond that oxygen and fluorine atoms established with hydrogen in their representations without identifying the partially negative and positive atoms but had difficulty in identifying the hydrogen bond that could be established between nitrogen and hydrogen. They once again identified the hydrogen bond in organic compounds with hydrogen atoms attached to the carbon atom in either the methyl group or the carbonyl group and oxygen atom. Another important finding of the study was that most of the students experienced the most difficulty in explaining the reason why the boiling point of ethyleenglycol was higher than that of ethanol in the pretests. Forty-six students in the pretests and twelve students in the posttests either failed to explain the reason or stated inaccurate and irrelevant interpretations. The students who obtained one point made inferences about properties, such as bond type, but could not or did not benefit from representations to explain further and focused only on the surface features. For instance, some students emphasized the attraction between nitrogen (N), oxygen (O), fluorine (F), and hydrogen, but they failed to explain what this meant or to relate this characteristic to an explanation of how establishing hydrogen bonds might affect the structure and properties of molecules. The manner of this explanation showed that the students had some understanding of the form of representations and could explain them but had difficulty in linking them to underlying causes or submicroscopic phenomena.

Approximately 9% of the students in the pretests and 23–35% of the students in the posttests earned two points. These students focused on macroscopic properties based on syntactic rules. Moreover, they showed the polarity property of the molecules with partial negativity and positivity on the molecule, correctly defined the bond establishments, and tended to focus on the explanation of particular concepts, such as electronegativity difference. When the students compared the physical features of molecules, they related intermolecular attraction force with "electronegativity" or "size" but did not explain in detail. No student obtained three points from Question 2 in the pretests. In contrast, in the posttest, seven students for e and f, six for b, four for a, and three for f followed the path of an entirely logical sequence to identify the polarity and non-polarity of the molecules and then compared the intermolecular attraction forces considering the properties of atoms while comparing the physical features of atoms. The sample representations and explanations of students are presented below in Table 4.

When the answers of students were analyzed, it can be observed that argumentation-based teaching was effective for eliminating misconceptions students have (e.g. student 9), constructing sound understanding (e.g. student 3), and allowing the more efficient usage of preknowledge (e.g. student 10). Thus, argumentation conducted via scaffolding with *bottom-up* can be inferred to have positive effects on the students' identification of hydrogen bonds and their understanding of the effects of hydrogen bond on the physical features of molecules.

DISCUSSION

Researchers have found that students commonly fail to obtain a deep conceptual understanding of the bonding concept and generally fail to integrate their mental models into a proper conceptual framework (Peterson et al., 1989; Taber, 1998). The current study validates that students had difficulty in understanding the formation of hydrogen bonds. According to the findings, nearly all the students in the pretests and nearly half the students in the posttests identified the hydrogen bond as the bond that hydrogen formed with great electronegative atom of nitrogen, oxygen, or fluorine. Nevertheless, they were unable to identify the hydrogen donor or acceptor atom. Moreover, they organized a list regarding the features of the bond they formed in their minds, such as "molecules with hydrogen bonding are infinitely miscible in water." According to Hurst (2002), oversimplified presentations mislead students, and they are barriers to learning.

Nahum et al. (2006) stated that teaching hydrogen bonding is a problem with the traditional approach. According to the researchers, the absolute definition that a hydrogen bond is the intermolecular bond that contains one of the atoms of nitrogen, oxygen or fluorine (NOF) generated "black and white" perceptions. The researchers thus suggested the following in the new approach: (a) "Emphasizing the unique characteristic of hydrogen bonds" and (b) "defining as intermolecular or intramolecular attractions created when a hydrogen atom bonded to an electronegative atom approaches a nearby electronegative atom, not only with nitrogen (N), oxygen (O), and fluorine (F)." According to them, a teaching approach should ensure a theoretical basis that results in a solid and meaningful understanding of the fundamental nature of hydrogen bonds, valid scientific explanations of certain phenomena, and a new assessment approach.

The study in which "bottom-up" teaching approach that followed a regular pattern starting from the properties of atoms in the molecule to the polarity of the molecule, range of bond strengths of intramolecular and intermolecular, properties and phenomena of matters with respect to aspects of bonding, and structure and limitations that Hurst (2002) and Taber (2002) suggested for the teaching of bonds was adopted, the effects of argumentation based teaching on the students' conceptual understanding of hydrogen bonds were analyzed. Throughout the discussions, the scaffolding of the teacher was fading as the possible activities progressed. In the argumentation in which the effects of hydrogen bond on the physical features of the molecules were discussed, the students were provided with numeric data, such as electronegativity, standard enthalpy of vaporization, and atomic number. In the course of the definition of hydrogen bonds, statements including the comparison of the physical features of the molecules on which hydrogen bonds were established were provided. The argumentative discourses in which the explanation scaffolding of the teacher was gradually reduced and the discussion was supported and directed by the following question, "What is the reasoning?," aimed that the students recognize not one factor alone, but the integrated effects of multiple factors can determine hydrogen bonding and its properties (Hurst, 2002; Tümay, 2015). The obtained findings confirm that these argumentation activities

Science Education International
32(3), 197-208
https://doi.org/10.33828/sei.v32.i3.3

Table 4: Student samples

Question	Before argumentation	After argumentation
2a	Student 3: Since stronger hydrogen bondings are present in ammonia molecules between nitrogen to hydrogen. Hydrogen bonding is formed when the compounds form from NOF and hydrogen	Student 3: The effective nuclear charge of hydrogen is +1 and that of nitrogen and phosphorus atoms is +5. They have a lone pair of electrons. The small size of the hydrogen atom and the high electronegativity of nitrogen pull on a valence electron of hydrogen resulting in a large δ+ charge in highly polar N–H bonds in NH3. A highly electronegative nitrogen atom has a large δ-charge and a lone pair of electrons, they are more strongly attracted to the another hydrogen. These highly polar bonds lead to strong hydrogen bonding between ammonia molecules. Phosphorus is larger and less electronegative than nitrogen; hence, the P–H bonds in PH3 are much less polar, and no hydrogen bonding between molecules occurs. These stronger intermolecular forces present between NH3 molecules require more energy to break individual molecules from one another than PH3 molecules
2b	Student 8: It arises from the differences between intermolecular attraction forces and from the established hydrogen bonds. It can also arise from the mass difference of molecules	Student 8: The protons in the oxygen core have a greater effect of attracting the outer shell electrons. Thus, the diameter of oxygen will be smaller than the sulfide atom with greater electronegativity. The oxygen in water attracts hydrogen more than the sulfide in hydrogen sulfide. Therefore, it is polarized more. Therefore, the vaporization heat and stability become greater than that of hydrogen sulfide
2c	Student 10: Hydrogen fluoride is in a stabile structure at high temperature. Thus, molecules are attached to one another at low temperature. This occurs due to the hydrogen bond. Hydrogen bonds are stronger than Van der Waals bonds; the substance whose intermolecular interactions are more powerful has higher boiling point. This special occasion derives from the greater electronegativity compared with that of fluorine	Student 10: Hydrogen bonds are formed between HF molecules. When Van der Waals bonds are separately considered, the boiling point of HCl whose mass is greater would be expected to be higher. Nonetheless, the fact that the boiling point of HF is higher than that of HCl indicates the efficiency of the hydrogen bond attraction The dissociation of HF in water is incomplete. Strong hydrogen bonding between HF molecules and also between HF and H2O molecules leads to the strong association of HF molecules in water solution and results in relatively few free hydronium H3O+ ions. Hence, HF is a weak acid
2d	Student 1: The substances establishing hydrogen bonds with water dissolve well in water. The –OH in the alcohol structure establishes hydrogen bonds	Student 1: More hydrogen attraction occurs between alcohol molecules. Electronegative oxygen atom pulls on an electron of hydrogen resulting in δ+ charge in alcohol and water molecules. Two electron pairs of oxygen attracted by deshielded proton of hydrogen. Hydrogen atoms act as a bridge linking high electronegative oxygen atoms to which they are bonded. Hydrogen bonds are established between alcohol and water molecules, too. Aldehyde is polar, and it dissolves in water. The oxygen atom of aldehyde within the carbonyl group and the hydrogen atoms in water molecule establish hydrogen bonds between aldehyde and water
2e	Student 11: Hydrogen bonding	Student 11: Methanol contains oxygen atom; methylamine contains nitrogen. Oxygen atom is more electronegative than nitrogen atom. Stronger hydrogen bonds are established between methanol molecules
2f	Student 7: Ethylene glycol has two –OH structures; ethyl alcohol has one. When the –OH structure increases, the boiling point of alcohols increases. That is why they dissolve more quickly	Student 7: Ethylene glycol has two –OH structures. It creates stronger hydrogen interaction with water

have positive effects on the students' conceptual understanding of hydrogen bonds. No student employed hydrogen bond and effective nuclear core, atomic diameter, and electronegativity factor while explaining the effects of this bond on the physical features of the molecules in the pretest, while approximately 13% of the students interpreted the polarity of the molecule, the direction of the electron distribution, and the force of the bond using the data about size, effective nuclear core, and electronegativity from the electronic configuration of the atoms in the molecule in the posttest. Note that, as in considerable previous research, the majority of the students had the rote knowledge that hydrogen bond was the one established between *an atom of nitrogen, oxygen or fluorine and hydrogen atoms*, but they could not explain the question "why." After the argumentation-based teaching approach, the number of students who correctly identified the partially positive and negative atoms using great electronegativity values in their explanations and drawings increased by 25%. The discussion groups were determined in accordance with the score distribution of the pretests. According to Heng et al. (2014), the quality of the argument is determined by the conceptual and argumentation levels of the students.

Before starting the argumentation activities, the concept test designed by the researcher was applied to grade 12 students in two classrooms. When composing the discussion groups, the points of all the students were ordered, and they were divided into four equal groups. The highest-scoring and low-scoring students in the second quartile and the lowest-scoring and high-scoring students in the third quartile were combined. Given that the level of the students' and conceptual understanding is important for the level of argumentation, the student groups that did not have wide gaps were combined instead of combining the highest-scoring and lowest-scoring students or grouping the high-scoring and low-scoring students among themselves. Since the lowest-scoring students had insufficient preknowledge, these students were not combined with the ones below the median value in the second quartile. The insufficiency of the preknowledge of these students did not allow the combination of them with the highest-scoring students as they would not volunteer in the discussion.

When the results of argumentations conducted with five activities in the context of hydrogen bonds along all seven chemistry classes were analyzed, it was observed that the conceptual knowledge of students regarding hydrogen bonds improved, but this improvement was higher for the students in Q_{2-4} than those in Q_{1-3}. The high-scoring students in the discussions contributed to the conceptual understanding of students in the second quartile with a rote understanding about hydrogen bonds and promoted a conceptual understanding among themselves. The least score rise was observed for the students in the third quartile, who developed syntactic rules regarding the hydrogen bond concept and its applications; the highest rise was observed for the students in the first quartile who had the lowest scores from the pretests. Thus, the preknowledge of the students can be inferred to be effective in enhancing the attainments of the discourse.

The argumentation activity in which the comparison of the reasons regarding the boiling points of ammonia, hydrogen fluoride, and water molecules was made was aimed at questioning their memorized and superficial comprehension about hydrogen bonds on the basis of only one factor considered as data, such as “the bond that hydrogen establishes only with an atom of nitrogen, oxygen or fluorine [NOF]” or the “as electronegativity difference increases, boiling point increases” notion with the question “What is the reasoning?,” followed with ensuring sound understanding that comprises multiple factors and emphasizing the unique characteristics of hydrogen bonds. Interactions between chemical bonds and particles fall under the grade 9 curriculum. However, the hydrogen bond topic places emphasis on ethyl alcohol, hydrogen fluoride, water, and ammonia molecules, which establish hydrogen bonds, solutions, and acid and base units in grades 10 and 11. Especially in the hydrogen fluoride molecule, the acidity force of hydrohalide is an elaborated example in grade 11. The acidity force of hydrohalide is described in the grade 11 chemistry coursebook as follows Ministry of Education (2012):

Making use of the electronegativity differences that we have found, we can order the bonds from more polar to less polar in the following manner: HF > HCl > HBr > HI. We should look at the bond strength to order the acidity force of these compounds from large to small. As the electronegativity of halogen decreases, the attraction force that it uses on hydrogen atom also decreases, that is, the strength of the bond decreases. Hence, HI acid in the acid series of HF, HCl, HBr, and HI gives its proton more easily compared to other compounds. HF acid is the halide acid that gives its proton the last in this acid series. Therefore, HI is the strongest and HF is the weakest acid in this series. The reason why F is weak is not the strength of the H–F bond. HF can simultaneously establish hydrogen bonds with H_2O molecules (p. 141).

In the study, the number of students that identified hydrogen bonds in HF was more than that who identified hydrogen bonds with the other molecules in the second part of Question 1. The fact that approximately 30 students were unable obtain any points in the pretests and 41 students failed to explain the difference between the boiling points of methylamine and methyl alcohol in Question 2 can imply that the “electronegativity difference” factor is not solely sufficient for the students to significantly understand hydrogen bonding. Moreover, the students had greater difficulty in identifying hydrogen bonds in organic molecules compared to those in inorganic molecules. The irrelevant explanation of the students (order efficient (acid > alcohol > aldehyde)) for Question 2 indicated that they focused on syntaxes rather than the meanings of concepts. One of the main reasons for this is the teaching, assessment, and evaluation process based on central examinations (Nahum et al., 2007).

CONCLUSION

“Hydrogen bonding” is an extensive topic that involves and is also involved in many other concepts; therefore, students should organize the construction of their already existing knowledge and present knowledge through logical relationships, which is of vital importance for the meaningful and deeper comprehension of symbolic, macro, and micro levels in chemistry teaching. The current study has revealed the contribution of scientific argumentation and the sufficient level of teacher support in generating and improving concept schemas. The limitations of this study are that it was short-term and focused on only one concept. Hence, extensive and long-term studies including all of the chemical bonds and intermolecular weak interactions should be conducted. Moreover, the variances of the conceptual and argumentative skills of students can be investigated through studies that combine low-scoring students or the high- and low-scoring groups regarding group distributions.

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REFERENCES

American Association for the Advancement of Science (AAAS). (1993). *Benchmarks for Science Literacy*. Oxford: Oxford University Press.

Awan, A.S., Iqbal, M.Z., Khan, T.M., Mahmood, T., and Mohsin, M.N. (2012). Pupils’ ideas in learning concept of the chemical bonding among Pakistan students. *International Journal of Applied Science and Technology*, 2, 139-146.

Birk, J.P., and Kurtz, M.J. (1999). Effect of experience on retention and elimination of misconceptions about molecular structure and bonding. *Journal of Chemical Education*, 76, 124-128.

Canpolat, N. (2002). Kimyasal denge ile ilgili kavramların anlaşılmasında

Science Education International
32(3), 197-208
https://doi.org/10.33828/sei.v32.i3.3

kavramsal değişim yaklaşımının etkinliğinin incelenmesi. In: *Doktora Tezi, Atatürk Üniversitesi Fen Bilimleri Enstitüsü* [Assessing the effectiveness of conceptual change in the understanding of concepts related to chemical equilibrium. In: *Doctoral Dissertation, Ataturk University Institute of Science and Technology, Erzurum*].

Chittleborough, G.D., and Treagust, D.F. (2008). Correct interpretation of chemical diagrams requires transforming from one level of representation to another. *Research in Science Education*, 38(4), 463-482.

Col, R.K., and Taylor, N. (2002). Mental models in chemistry: Senior chemistry students' mental models of chemical bonding. *Chemistry Education: Research and Practice in Europe*, 3, 175-184.

Cross, D., Taasoobshirazi, G., Hendricks, S., and Hickey, D.T. (2008). Argumentation: A strategy for improving achievement and revealing scientific identities. *International Journal of Science Education*, 30, 837-861.

Driver, R., Newton, P., and Osborne, J.F. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, 83(4), 287-312.

Erduran, S., and Jiménez-Aleixandre, M.P. (2007). *Argumentation in Science Education: Perspectives from Classroom-Based Research*. Berlin, Germany: Springer.

Haigh, M., France, B., and Gounder, R. (2011). Compounding confusion? When illustrativepractical work falls short of its purpose-a case study. *Research in Science Education*, 42, 967-984.

Henderleiter, J., Smart, R., Anderson, J., and Elian, O. (2001). How do organic chemistry students understand and apply hydrogen bonding? *Journal of Chemical Education*, 78(8), 1126-1130.

Heng, L.L., Surif, J., and Seng, C.H. (2014). Individual versus group argumentation: Student's preformance in a Malaysian context. *International Education Studie*, 7(7), 109-124.

Hurst, O. (2002). How we teach molecular structure to freshmen. *Journal of Chemical Education*, 79, 763-764.

İnan, H.Z., and İnan, T. (2015). 3Hs education: Examining hands-on, heads-on and hearts-on early childhood science education. *International Journal of Science Education*, 37, 1974-1991.

Karasavvidis, I. (2002). Distributed cognition and educational practice. *Journal of Interactive Learning Research*, 13, 169-188.

Levy Nahum, T., Hofstein, A., Mamlok-Naaman, R., and Bar-Dov, Z. (2004). Can final examinations amplify students' misconceptions in chemistry? *Chemistry Education: Research and Practice in Europe*, 5, 301-325.

Levy Nahum, T., Mamlok-Naaman, R., Hofstein, A., and Krajcik, J. (2007). Developing a new teaching approach for the chemical bonding concept aligned with current scientific and pedagogical knowledge. *Science Education*, 91, 579-603.

Levy Nahum, T., Mamlok-Naaman, R., Hofstein, A., and Taber, K.S. (2010). Teaching and learning the concept of chemical bonding. *Studies in Science Education*, 46(2), 179-207.

Luckin, R. (1998). Knowledge construction in the zone of collaboration: Scaffolding the learner to productive interactivity. In: Bruckman, A., Guzdial, M., Kolodner, J., and Ram, A. (Eds.), *International Conference of the Learning Sciences*. Atlanta, Georgia: AACE. pp. 188-194.

Ministry of Education (MoNE). (2012). *Ortaöğretim Kimya 11 Ders Kitabı* [*Secondary Chemistry 11 Textbook*]. Ethiopia: Mega Publishing.

Naaman, R., and Vager, Z.J. (1999). Dipole moment of non-rigid molecular system: The dipole moment of hydrochloric dimmers. *Journal of Chemical Physics*, 110, 359-362.

Nahum, T.L., Mamlok-Naaman, R., Hofstein, A., and Krajcik, J. (2006). Developing a new teaching approach for the chemical bonding concept aligned with current scientific and pedagogical knowledge. *Science Education*, 9, 579-603.

Nakhleh, M.B. (1992). Why some students don't learn chemistry. *Journal of Chemical Education*, 69, 191-196.

Nussbaum, E.M., Sinatra, G.M., and Poliquin, A. (2008). Role of epistemic beliefs and scientific argumentation in science learning. *International Journal of Science Education*, 30(15), 1977-1999.

Osborne, J.F. (2001). Promoting argument in the science classroom: A rhetorical perspective. *Canadian Journal of Science, Mathematics, and Technology Education*, 1(3), 271-290.

Peterson, R.F., Treagust, D.F., and Garnett, P. (1989). Development and application of a diagnostic instrument to evaluate grade-11 and grade-12 students' concepts of covalent bonding and structure following a course of instruction. *Journal of Research in Science Teaching*, 26(4), 301-314.

Prain, V., Tytler, R., and Peterson, S. (2009). Multiple representation in learning about evaporation. *International Journal of Science Education*, 31(6), 787-808.

Schmidt, H.J., Kaufmanna, B., and Treagust, D.F. (2009). Students' understanding of boiling points and intermolecular forces. *Chemistry Education Research and Practice*, 10, 219-226.

Şekerci, A.R. (2015). Development of diagnostic branched tree test for high school chemistry concepts. *Oxidation Communications*, 38, 1060-1067.

Şekerci, A.R., and Canpolat, N. (2014). Impact of argumentation in the chemistry laboratory on conceptual comprehension of Turkish students. Educational process. *International Journal*, 3(1-2), 19-34.

Taber, K.S. (1998). An alternative conceptual framework from chemistry education. *International Journal of Science Education*, 20(5), 597-608.

Taber, K.S. (2002). *Chemical Misconceptions: Prevention, Diagnosis and Cure, Theoretical Background*. Vol. 1. United Kingdom: Royal Society of Chemistry.

Tan, K.C.D., and Treagust, D.F. (1999). Evaluating students' understanding of chemical bonding. *School Science Review*, 81(294), 75-83.

Tümay, H. (2015). Prospective chemistry teachers' mental models of vapor pressure. *Chemistry Education and Research Practice*, 15, 366-379.

Tytler, R. (2007). *Re-Imagining Science Education*. Camberwell: Australian Council for Educational Research, Australian Council for Educational Research.

Vinner, S. (1997). The pseudo-conceptual and the pseudo-analytical thought processes in mathematics learning. *Educational Studies in Mathematics*, 34, 97-129.

Yayon, M., Mamlok-Naaman, R., and Fortus, D. (2012). Characterizing and representing student's conceptual knowledge of chemical bonding. *Chemistry Education Research and Practice*, 13, 248-267.

APPENDIX

Appendix 1: Periodic table including some data regarding 20 elements

H			**^{a}Atomic number**				**He**
^{a}1			**^{b}Electronegativity**				**2**
^{b}21			**^{c} Electronic configuration**				**-**
^{c}$1s^1$							**-**
^{d}1			**^{d}Nuclear charge**				**-**
^{e}+1			**^{e}Effective nuclear charge**				**+2**
Li	**Be**	**B**	**C**	**N**	**O**	**F**	**Ne**
3	4	5	6	7	8	9	10
1.0	1.5	2.0	2.5	3.0	3.5	4.0	-
$1s^22s^1$	-	-	-	-	$1s^12s^22p^4$	-	-
3	-	-	-	7	8	-	10
-	+2	-	+4	-	+6	-	+8
Na	Mg	Al	Si	P	S	Cl	Ar
11	12	13	14	15	16	17	18
0.9	1.2	1.5	1.8	2.1	2.5	3.0	-
$1s^22s^22p^63s^1$	-	-	$1s^22s^22p^63s^23p^2$	-	-	-	-
11	-	-	14	-	16	-	18
+1	-	-	+4	+5	-	+7	-

APPENDIX 2

Samples of Discussions

Activity 3: Discuss the reasons why hydrogen sulfide molecules displayed acidic property even though the boiling point of water is higher than that of hydrogen sulfide.

Activity 4: Compare the normal boiling point of diluted ethyl alcohol solution, pure ethyl alcohol, and pure water.

Observe the normal boiling of substances.

Pure water (100°C) > ethyl alcohol solution (78.3°C) >pure ethyl alcohol (78.17°C)

Do you agree with the data? If not, then revise your comparison.