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Effectiveness of Instruction Based on Constructivist Approach on Students' Understanding of Chemical Bonding Concepts

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ABSTRACT *The main purpose of this study was to investigate the effect of instruction based on constructivist approach on ninth-grade students' understanding of chemical bonding concepts and their attitudes toward chemistry as a school subject. The contribution of students' science process skills to their understanding was also investigated and gender differences in terms of understanding chemical bonding concepts and attitudes toward chemistry as a school subject were examined. Forty-two ninth-grade students from two classes of a chemistry course taught by the same teacher participated in the study. The classes were randomly assigned as control and experimental groups. Students in the control group were instructed by traditionally designed chemistry instruction whereas students in the experimental group were taught by instruction based on constructivist principles. This instruction was mainly grounded on Yager's (1991) constructivist teaching strategy. The results indicated that instruction based on constructivist approach caused a significantly better acquisition of scientific conceptions related to chemical bonding and produced significantly higher positive attitudes toward chemistry as a school subject than the traditionally designed chemistry instruction. Science process skill was also a strong predictor in understanding of the concepts related to chemical bonding. On the other hand, no significant effect of gender on the understanding of chemical bonding concepts and attitudes toward chemistry as a school subject was found.*

KEY WORDS: *Constructivist approach, chemical-bonding concepts, attitudes toward chemistry.*

Introduction

Researchers in science education focused on students' conceptions before and after instruction and investigated what could be done to facilitate conceptual change in students' ideas (Smith, Blakeslee, & Anderson, 1993; Osman & Hannafin, 1994; Jones, Carter & Rua, 2000; Teichert & Stacy, 2002). Thus, the importance of understanding how students learn scientific concepts has been stressed. It has been accepted that students develop ideas about world before they are formally taught and these ideas play an essential role in the learning process. Students' ideas are given different names such as children's science, alternative frameworks, alternative conceptions, or misconceptions (Driver & Oldham, 1986). Generally, the term misconceptions implies students' mistaken answers to a particular situation; their ideas which cause mistaken answers about a particular situation or their beliefs about how the world works are different than those of the scientists (Dykstra, Boyle, & Monarch, 1992).

Students have difficulties in understanding most of the concepts in chemistry and hold misconceptions, which prevent meaningful learning (Staver & Lumpe, 1995; Renstrom, Anderson, & Morton, 1990; Hesse & Anderson, 1992; Pardo & Solaz-Patolez, 1995; Garnett, 1992). In chemistry, chemical bonding is one of the basic topics; the substances in nature and the changes they undergo can be explained by chemical bonding. Understanding chemical bonding concepts is important in chemistry in order to comprehend the nature of the chemical reactions and some physical properties, such as boiling points. Chemical bonding is an abstract concept that cannot be applied to everyday life directly and many students face difficulties in comprehending this concept. They cannot relate microscopic world to macroscopic changes (Coll & Treagust, 2003; Harrison & Treagust, 2000; Nicoll, 2001; Tan & Treagust, 1999; Ben-Zvi, Eylon & Silberstein, 1987; Valanides, 2000a, 2000b; Valanides, Nicolaidou, & Eilks, 2003). For example, several researchers (Ben-Zvi, Eylon, & Silberstein, 1987; Valanides, 2000a, 2000b; Valanides et al., 2003) reported that students could not differentiate between physical and chemical change at the microscopic level. The students do not view chemical reactions as interactive; they simply view chemical reactions as a process of addition of reactants to form products rather than as a process of bond making and bond breaking (Valanides et al., 2003). In addition, understanding chemical bonding requires some physics topics, such as energy and force, in which students have difficulties to correctly conceptualize them. As a result, they hold many misconceptions related to chemical bonding concepts (Taber, 1995). Most students cannot understand why and how bonding occurs. They confuse atoms and molecules, fail to consider octet rule, cannot relate polarity with electro-negativity and cannot distinguish between ionic and covalent bonding (Nicoll, 2001). In a similar study, Taber (1994) stated that students believe that the atomic electronic configuration determines the number of ionic bonds formed; bonds are only formed between atoms that donate and accept electrons. It was stated that students could not understand nature of chemical bonding. They have misconceptions that metals and nonmetals form molecules that is, atoms of a metal and a nonmetal share electrons to form molecules; a metal is covalently bonded to a nonmetal to form a molecule; metals and nonmetals form strong covalent bonds; ionic compounds exist as molecules formed by covalent bonding and the strength of intermolecular forces is determined by the strength of the covalent bonds present in the molecule (Harrison & Treagust, 2000; Tan & Treagust, 1999; Peterson, Treagust, & Garnett, 1989).

On the other hand, most students do not consider metallic bond as a chemical bond. They believe that metals do not have any bonds since all atoms are the same; there are some interactions in metals, but there is not proper bonding, or metals have covalent and/or ionic bonding. These students do not consider the existence of bonds other than covalent or ionic. Some think that metallic bonding occurs only in alloys, holding the idea that metallic bonding exists between two different metal atoms (Taber, 2003). One of the most common misconceptions among students is about the structure of ionic compounds, specifically the structure of NaCl. Butts and Smith (1987) stated that most students cannot understand the three dimensional nature of ionic bonding in NaCl. Students think that NaCl exists as molecules and these molecules are held together by covalent bonds. Other students think that Na and Cl atoms are bonded covalently and that the ionic bonds between these molecules produce the crystal lattice. There are also other studies (Coll & Treagust, 2003; Coll & Taylor, 2001; Tan & Treagust, 1999) supporting that students have difficulty in understanding structure of ionic compounds.

Students' misconceptions interfere with subsequent learning and thus new knowledge cannot be connected to students' existing cognitive structure (Teichert & Stacy, 2002; Boo & Watson, 2001; Appleton, 1993; Nakhleh, 1992) and meaningful learning does not occur. In meaningful learning, the learner makes connections between what he/she already knows and new potentially meaningful information is integrated in his/her cognitive structures. For meaningful learning to occur, there should be two conditions. Firstly, new knowledge should have potential meaning, the learner should have relevant concepts to anchor the new ideas, and, secondly, the learner should incorporate the new knowledge in a nonarbitrary, non-verbatim way. When one or more of these requirements are not met, rote learning or verbatim memorization occurs. In rote learning, students do not develop hierarchical frameworks of successively more inclusive concepts. Instead, they accumulate isolated propositions in their cognitive structures. This causes poor retention and difficulties in retrieving the new knowledge when needed (Ausubel, 1968). Therefore, one of the purposes of science education is to change one's conceptions by integrating new conceptions, restructuring or modifying existing conceptions for new conceptions. This process is usually termed as conceptual change.

The necessary conditions for conceptual change are disequlibration, assimilation and accommodation, terms introduced by Piaget (1950). Assimilation refers to the recognition of a physical or mental event that fits an existing conception. When an event could not be assimilated under the held conceptions, then accommodation occurs. For accommodation to occur, a student must enter a state of cognitive disequilibrium. If the result of an event does not fit the student's existing conceptions, this situation disequilibrates the student with respect to his/her current conceptionss. If students can assimilate the concepts presented, then there is no disequilibration and no conceptual change. Conceptual change can be achieved by disequilibration, which is the result of an unexpected or discrepant event. Therefore, instruction should aim to disequilibrate students for conceptual change (Dykstra, 1992).

A conceptual change model proposed by Posner, Strike, Hewson, and Gertzog (1982) states that the first step is to create a conflict between students' existing ideas and scientific knowledge (*dissatisfaction*); then, the students consider new information seriously. Second, a new conception must be *intelligible.* Intelligibility also requires constructing or identifying a coherent representation of a passage or theory. Third, a new conception must be *plausible*; a new conception must have capacity to solve the problems generated by its predecessors. Fourth, a new concept must be *fruitful.* It must have potential to open up new areas of inquiry. It leads to new insights and discoveries. The extent to which the conception meets these conditions is named as the status of a person's conception. The more conditions that a conception meets, the higher is its status. Conceptual change does not occur without changes in the status of existing conceptions. Learning occurs when the status of a new conception rises, or, in other words, when a student understands a new concept, accepts it, and realizes its usefulness. If a new conception conflicts with the existing knowledge, the student should lower the status of his/her existing knowledge in order to accept new knowledge (dissatisfaction) (Hewson, 1996).

Different researchers use different terms for conceptual change but there is a common ground between the various perspectives of conceptual change. Creating links is an important feature of conceptual change theory, otherwise, there is no difference between conceptual change and simple rote learning. Conceptual change concerns with restructuring of existing knowledge (Tyson, Venville, Harrison, & Treagust, 1997). Therefore, instruction should consider students' current structure that affects their construction of knowledge. If students are provided with activities in which they use their existing knowledge to overcome obstacles or contradictions, cognitive reorganization takes place. Activities for raising the status of a concept cause conceptual change. These activities may involve presenting and developing the ideas, providing examples, applying them in other situations, giving different way of thinking about them, and linking them to other situations. Also, activities for lowering the status of ideas lead to conceptual change. These activities may include exploring inadequacy of the ideas and discussing situations in which the ideas fail to explain phenomena. Status raising and status lowering activities can overlap (Hewson, 1996).

These types of activities have been considered by constructivist approach, which stresses the importance of students' existing ideas and active use of knowledge. The main goal of constructivism is to develop higher-order abilities, such as problem solving, critical thinking, reasoning and reflective thinking. These abilities can be promoted through activities in which students actively use their previous knowledge. The core commitment of constructivism is that knowledge cannot be transferred into the students' minds. Instead students actively construct their own meanings from the words or visual images they hear or observe. They form, elaborate and test new knowledge until they become satisfied. Knowledge develops and continues to change with the activity of the learner. Then, learning occurs by changing and organizing cognitive structures and changing the status of a conception. Students create new meaning for scientific concepts by reflecting on their mental activity. The fact that they use their existing knowledge actively in order to explain new knowledge allows conceptual change (Driscoll, 1994; Steffe, P., & Gale, J., 1995; Driver, Asoko, Leach, Mortimer, & Scott, 1994). Students should activate and utilize their prior knowledge in order to integrate new knowledge into their cognitive structures rather than just recall information. If students become dissatisfied with their existing knowledge, they reorganize their cognitive structures in a meaningful way in order to make the new knowledge more understandable and plausible (Reif & Larkin, 1991). Students should engage in metacognitive reflection, rethinking their old ideas and comparing them with the new knowledge in order for conceptual change to occur (Pintrich, Marx, & Boyle, 1993).

On the other hand, a social constructivist perspective favors the idea that scientific understanding is constructed when students engage in social talk and activity about shared problems or tasks. Social interaction stimulates understanding and better interpretation of the phenomena. Activities supported by group discussions provide reflection of ideas and teachers' role should be to facilitate and encourage this reflection (Driver et. al., 1994).

Researchers developed a lot of teaching strategies based on constructivist approach, such as Driver's constructivist teaching sequence (Driver & Oldham, 1986), learning cycle approach (Stepans, Dyvhe & Beiswenger, 1988), conceptual change model (Posner et al., 1982), and bridging analogies approach (Brown & Clement, 1989). Yager (1991) proposed constructivist teaching strategies such as:

1. Invitation: Ask questions, consider responses to questions, note unexpected phenomena, identify situations where student perceptions vary.
2. Exploration: Brainstorm possible alternatives, look for information, experiment with material, discuss solutions with others, engage in debate and analyze data.
3. Proposing explanations and solutions: Construct and explain a model, review and critique solutions, integrate a solution with existing knowledge and experiences.
4. Taking action: Make decisions, apply knowledge and skills, share information, ask new questions.

In the present study, Yager's (1991) constructivist teaching strategies were employed in the teaching approach used to teach chemical bonding concepts.

In studies where constructivist approach was used, it has been showed that constructivist-teaching strategies were effective in enhancing students understanding and achievement. For example, Niaz (1995) studied a dialectic constructivist framework based on cognitive conflict for freshman chemistry students. This framework stresses the understanding of phenomena within their complex relationships. It does not isolate and separate processes; it does use interrelationship to one another. It was reported that students exposed to cognitive conflicts were more successful than students who studied the same content in a traditional way. Also, Caprio (1994) examined the effectiveness of a constructivist approach compared with the traditional lecture-lab method. It was concluded that students taught by constructivist methodology had significantly better exam grades. Moreover, these students seemed more confident in their learning.

Research studies revealed that constructivist teaching strategies are useful not only for improving achievement but also for helping students construct their own views about science and develop thinking ability. Carey, Evans, Honda, Jay, and Unger (1989) concluded that prior to the constructivist methodology that included scientific inquiry, most students viewed science as a way of understanding facts about the world. After the constructivist methodology, most of the students viewed scientific inquiry as a process guided by questions and ideas. Tynjala (1998) showed that students following constructivistic learning develop better ability to apply knowledge and develop their thinking and communication skills.

Recent research studies (Hearty, Beall, & Scharmann, 1985; Simpson, & Oliver, 1990; Lee & Burkam, 1996) indicated that students' attitudes toward science is strongly related to their achievement in science. Attitudes can be defined as predispositions to respond positively or negatively to objects, such as ideas, events, places or people. It covers enjoyment, like-dislike, interest, confidence, perception, value, and competence (Hill & Atwater, 1995). It should also be considered as an outcome of science education. Since attitudes form and change during a lifetime of a person, facilitating this process should be an important part of the work of science teachers (Koballa, 1992). It was found that students hold more positive attitudes toward science when they are actively involved in the learning process. Students prefer science teaching and learning in which they take responsibility and control of their learning. Being responsible for their own knowledge construction induces students to be mentally and emotionally engaged in the learning process. Teaching strategy plays an essential role in determining students' attitudes toward science (Ebenezer & Zoller, 1993). Use of hands-on laboratory program improves students' attitudes toward science and enhances their achievement (Freedman, 1997). Extracurricular science activities cause students to see science more enjoyable, more interesting, and more attractive (Maoz & Rishpon, 1990). Since constructivist strategies promote active involvement of students, they are expected to lead to more positive attitudes toward science.

On the other hand, science process skills are important for understanding scientific concepts. Science process skills involve identifying variables and stating hypotheses, designing investigations, graphing and exploring data, explaining results, and drawing conclusions. In the literature, it has been indicated that learning science requires high cognitive skills (Lazarowitz, 2002; Sungur, Tekkaya, & Geban, 2001).

Purpose

The primary goal of the present study was to investigate the effectiveness of instruction based on constructivist approach (ICA) over traditionally designed chemistry instruction (TDCI) on ninth-grade students' understanding of chemical bonding concepts and on their attitudes toward chemistry as a school subject, while the contribution of students' science process skills to understanding of chemical bonding concepts was also investigated. In addition the effect of gender difference on students' understanding of chemical bonding concepts and their attitudes toward chemistry as a school subject was examined.

Methodology

Subjects

The participants were 42 ninth-grade students from two classes of a chemistry course taught by the same teacher. Each class was taught by a different instructional method. Data were collected from 22 students taught by a constructivist approach and from 20 students taught by traditional chemistry instruction.

Instruments

Chemical Bonding Concept Test (CBCT)

This test was developed by the researchers. The content was determined by examining instructional objectives for the chemical bonding unit and related literature. The questions in the test were developed from the literature related to students' alternative conceptions or misconceptions with respect to chemical bonding (Butts & Smith, 1987; Tan & Treagust, 1999; Birk & Kurtz, 1999; Coll & Taylor, 2001; Nicoll, 2001) and a set of pilot interviews with some classroom teachers.

During the interviews, teachers answered questions related to their experiences about topics where students usually face difficulties. The test consisted of 18 items. The questions required students to predict about a situation where there was a possibility to give a wrong answer caused by students' misconceptions. The test included two parts. The first part of the test consisted of two-tier questions and examined students' understanding of chemical bonding. Each question had two parts: *a response section* in which students were asked to mark only one of two possible answers and *a reason section* in which students were asked to select the correct reason for the answer in the previous part. The second part of the test consisted of multiple-choice questions. Each question in this part had one correct answer and three distracters. The distracters of an item reflected students' alternative conceptions or misconceptions identified in the literature or during the interviews with chemistry teachers. Content validity of the test was established by a group of experts in science education and chemistry. The course instructor checked the appropriateness of the items in terms of the extent to which the test sampled the objectives of the bonding unit of the chemistry course. The reliability coefficient of the test or its internal consistency (Cronbach alpha) was found to be 0.72. The test was administered to students of both groups as a pre-test to control students' understanding of chemical bonding concepts. It was then administered as a post-test and the results were used for comparing the effects of two instructional strategies on understanding of chemical bonding concepts. The two teaching strategies were Instruction based on Constructivist Approach (ICA) and Traditionally Designed Chemistry Instruction (TDCI).

Attitude Scale Toward Chemistry (ASTC)

A scale developed by the researchers was used to measure students' attitudes toward chemistry as a school subject. This scale consisted of 15 items in a 5-point Likert-type scale (fully agree, agree, undecided, partially agree, fully disagree). The internal consistency reliability of the scale was found to be 0.83. This test was given to students in both groups after the instructional treatment.

Science Process Skill Test (SPST)

The test was originally developed by Okey, Wise, and Burns (1982). It was translated and adapted into Turkish by Geban, Aşkar, and Özkan (1992). This test contained 36 four-alternative multiple-choice questions. It was given to all students in the study. The reliability of this test computed by Cronbach alpha estimates of internal consistency was found to be 0.85. This test measured intellectual abilities of students related to identifying variables, identifying and stating hypotheses, operationally defining variables, designing investigations, and graphing and interpreting data.

Treatment

The study was conducted over a four-week period. One of the classes was instructed through the CIA (experimental group) and the other through TDCI (control group). Both groups were instructed by the same teacher on the same content of chemistry course. During the treatment, the chemical bonding topics were covered as a part of the regular classroom curriculum in the chemistry course. The classroom instruction of the groups was three 40-minute sessions per week.

The topics covered were definition of a bond, formation of bonds, types of bonds (intramolecular and intermolecular), polarity and properties of bonds.

At the beginning, both groups were administered CBCT and ASTC to determine whether there was any difference between two groups with respect to their understanding of chemical bonding concepts and attitudes toward chemistry prior to instruction. Also, the students were administered SPST to determine their science process skills.

In the control group, the teacher used lecture and discussion methods to teach concepts and used algorithmic approaches with solving problems. The students were required to read the related topic of the lesson from the textbook prior to the hour-long lesson. The teacher described and defined the concepts and after teacher's explanation, the concepts were discussed by teacher-directed questions. The instruction was mainly structured by the teacher without consideration of students' misconceptions.

The experimental group was instructed using ICA. The ICA was based on Yager's (1991) constructivist teaching strategy. Thus, as a first step (invitation), the teacher asked students some questions at the beginning of the instruction in order to activate their prior knowledge and promote student-student interaction and agreement before presenting the concept. For example, the teacher began the instruction with a question asking what a chemical bond means.

As a second step (exploration), students were allowed to discuss the question in groups by using their previous knowledge related to atoms. The teacher created the groups based on their grades in the last semester. The groups consisted of four or five students. Each group involved high, medium, and low achieving students. The students discussed the question in groups by considering their knowledge on structure of atoms. During the discussion, students had the opportunity to express their ideas and realized their peers' thoughts. They defended their ideas when there were different from other ideas in a group. At the end of the discussion, each group was supposed to give a common answer to the teacher. For the question asked in the invitation step, most students thought that bonds were "things" that hold atoms together, but they could not explain exactly what the "things" were. This step was designed to create cognitive conflict(s) following Posner et al.'s (1982) conceptual change model. During discussions, students became aware of their ideas and realized some inconsistencies or gaps in their reasoning and therefore dissatisfaction occurred.

As a third step (proposing explanations and solutions), the teacher got the answers from each group. Based on their answers, he explained the concept. He emphasized the common misconceptions and other topics where students faced difficulties. He explained why the students' conceptions were wrong. He presented scientifically correct explanation by using analogies and examples. For the question asked in step 1, after the teacher got the students' responses, he wanted students to explain what they meant by saying "things." However, the groups could not explain it. Then, the teacher introduced bonding concepts. While explaining what a chemical bond was, he constructed similarities between magnets and bonds; the fact that like poles repel each other and unlike poles attract each other is similar to the attraction and repulsion between electric charges or magnet poles. There are attractions between particles of two atoms that lead to chemical bonding and hold the structure together. This step supports conceptual change described by Posner et al. (1982). Since the teacher stated clearly what a chemical bond is by using magnets, emphasizing interactions and stressing students' preconceptions, the concept became intelligible and plausible to the students. In addition, the students realized that they could use this explanation for finding solutions to other questions; in this way, Posner et al.'s (1982) last condition (fruitfulness) was achieved.

As a last step (taking action), the teacher concluded that chemical bonds are electrostatic forces and asked a new question which was: Why chemical bonds are formed? Before presenting each new concept, the teacher asked questions which students could answer by using their previous knowledge. Some questions were: What is the reason that atoms form bonds? Why do metals and nonmetals or nonmetals and nonmetals form bonds? Why is table salt hard solid? Why does table salt conduct electricity when dissolved in water? Why is wax a low melting substance? Why are metals shiny? All of the questions reflected students' misconceptions found from the literature (Butts & Smith, 1987; Tan & Treagust, 1999; Birk & Kurtz, 1999; Coll & Taylor, 2001; Nicoll, 2001). Yager's (1991) constructivist teaching strategy was used for each question in a cyclic way.

The researcher observed both groups randomly during treatment and confirmed that the teacher fulfilled the requirements of treatment. At the end of the treatment, all students were given CBCT and ASTC as post-tests in order to compare the effectiveness of ICA over TDCI.

Results

At the beginning of the instruction, there was no significant difference between the two groups in terms of understanding chemical bonding concepts ($\underline{t}(40) = 0.932$, $\underline{p} > 0.05$), attitudes toward chemistry as a school subject ($\underline{t}(40) = 0.670$, $\underline{p}. > 0.05$), and science process skills ($\underline{t}(40) = 1.130$, $\underline{p}. > 0.05$).

A 2 (gender) X 2 (groups) analysis of covariance (ANCOVA) was used to determine the effectiveness of the instructional methods related to chemical bonding concepts by controlling the effect of students' science process skills as a covariant. In addition, by using this analysis, the effect of gender difference on students' understanding of chemical bonding concepts was explained. Also, this statistical technique revealed the contribution of science process skills to the variation in understanding chemical bonding concepts.

The two-way analysis of covariance (ANCOVA) showed that there was a significant difference between the post-test mean scores of the students taught by ICA and those taught by TDCI with respect to the understanding of chemical bonding concepts ($\underline{F}(1,37)=71.190$; $\underline{p}<0.05$). The ICA group scored significantly higher than TDCI group ($\bar{X}$ (ICA) = 12.272, $\bar{X}$ (TDCI) = 8.400).

After instruction, students in the experimental group became more comfortable with the chemical bonding concepts. For example, when students were asked whether $CaCl_2$ was an ionic compound in the first part of the question and in the second part, they were asked to state the reason of their answer to the first part, 58% of the students taught by ICA seemed to be comfortable with the right idea that $CaCl_2$ is an ionic compound, because there is an electron transfer. On the other hand, only 37% of the students taught by TDCI were able to identify whether $CaCl_2$ is an ionic after treatment. The common misconceptions in this group were that electrons are shared between atoms (28%) and that the ability of calcium atom to attract electrons is similar to that of chlorine atom (11%). Based on this item, it can be inferred that students confused the formation of ionic and covalent bonding. In another question, in the first part, students were supposed to state whether the sentence "When NaCl dissolves in water, there are still ionic bonds between sodium and chlorine atoms in solution" was correct or not. In the second part of the same question, the students were asked to state their reasoning for the previous part. Although both groups showed low achievement for this question, the majority of the TDCI group students thought that NaCl is still molecular in water, which was wrong. Only 5% of the students in the TDCI group gave correct answer to the two parts of this question, whereas 28% of the students in the ICA group answered it correctly stating that NaCl exists as a discrete pair of Na^+ and Cl^- after instruction.

Among control group students, the common misconceptions were that NaCl exists as molecules (55.6%), and positive charge on sodium ions are neutralized by gaining electrons from chloride ions (22.2%). Students were also asked to give a reason to the following question: "Why does not N_2 decompose at high temperatures although its boiling point is very low (-147 ^{0}C)?" Students were supposed to state that the boiling point of N_2 is very low (-147 ^{0}C), on the other hand, at high temperatures, it does not decompose due to intramolecular forces because triple bond is very strong compared to intermolecular (Van der Waals) forces. After instruction, 40% of the students answered correctly both parts of this question. However, after instruction, only 18% of the students in the TDCI group answered the two parts of this question correctly. Most of the students confused intermolecular and intramolecular forces, they thought that N_2 has strong intermolecular forces, thus it does not decompose at high temperatures (28%). When students were asked why boiling point of NH_3 is higher than that of CH_4, 55% of the students in the ICA, group stated correctly that the boiling point of NH_3 is higher than that of CH_4 because there are hydrogen bonds between NH_3 molecules. However, only 17% of the students in the TDCI group answered the same question correctly. Again in this question, students confused intermolecular and intramolecular forces 33% of the control group students stated that NH_3 contains covalent bonds, and thus it has higher boiling point, while 28% of the students in this group thought that CH_4 has covalent bonds, and, for this reason, it has lower boiling point. 22% of the students claimed the existence of Van der Waals forces in CH_4 molecules as a reason for low boiling point; These questions caused striking difference between the percentages of students' the correct responses in the experimental group and the control group. After instruction, percentage of average correct response of experimental group students was 67.10% and that of control group students was 47.85%.

The findings also revealed that there was no significant mean difference between male and female students in terms of understanding chemical bonding concepts ($\underline{F}(1,37)=2,141$; $\underline{p}>0,05$). The mean post-test scores were 10.42 for females and 10,44 for males. In addition, there was no interaction between gender and treatment with respect to students' understanding of chemical bonding concepts ($F(1,37)=0.716$; $p>0.05$).

On the other hand, there was a significant contribution of science process skills on students' understanding of chemical bonding concepts ($F(1,37)=134.850$, $p<0.05$).

In order to test the effect of treatment and gender on students' attitudes toward chemistry as a school subject, a 2 (gender) x 2 (treatment) analysis of variance (ANOVA) was used. The results showed that there was a significant mean difference between students taught through instruction based on constructivist approach and traditionally designed chemistry instruction with respect to attitudes toward chemistry as a school subject ($F(1,38)=5.731$; $p<0.05$). Students instructed by instruction based on constructivist approach had more positive attitudes ($\bar{X}$=57,318) than students taught by traditionally designed chemistry instruction ($\bar{X}$=53,150).

Also, there was no significant mean difference between male and female students with respect to attitudes toward chemistry as a school subject ($F(1,38)= 3{,}246$; $p>0{,}05$). In addition, no significant interaction between gender difference and treatment was found ($F(1,38)=0.444$; $p>0.05$).

Discussion

The main purpose of this study was to compare the effectiveness of two instructional approaches (a constructivist approach and a traditionally designed chemistry instruction) on ninth-grade students' understanding of chemical bonding concepts and their attitudes towards chemistry as a school subject, while the contribution of students' science process skills to their understanding and gender differences were also examined. The results indicated that students taught by the constructivist instructional approach had a significantly better acquisition of scientific conceptions related to chemical bonding and less misconceptions than the students taught by the traditionally designed chemistry instruction. Chemical bonding is a very abstract topic that also requires some knowledge of physics concepts to fully comprehend chemical bonding concepts. Thus, students could not easily comprehend the nature of chemical bonding. Most students initially expressed ideas indicating that bonds were 'material things' connecting atoms together rather than electrostatic forces. They also held the conception that a bond should be either ionic or covalent. Evidently, teachers should focus on their students' conceptions when teaching chemical bonding concepts and attempt to help them overcome possible difficulties in understanding chemical bonding and other related concepts. Students should become aware of their existing ideas, and teachers should provide experiences and appropriate scaffolding leading to a restructuring of their cognitive schemas.

In the present study, a constructivist teaching strategy (Yager, 1991) was compared with a traditionally designed chemistry instruction. In the constructivist teaching strategy, as a first step (invitation) the teacher raised questions to activate students' prior conceptions that were subsequently discussed within groups of students (exploration). Thus, the teacher created a learning environment where students could use their prior knowledge and become aware of their already existing conceptions. During discussion with their peers, the students tried to make connections between their existing knowledge and the new concept. For example, students' knowledge about the structure of an atom helped them understand why atoms bond to each other. Students realizing that their existing ideas were not effective in explaining the new situation took the new knowledge into serious consideration. Students in this group were encouraged to apply their experiences to new situations and, through group discussion and appropriate scaffolding, they tried to find appropriate answers to their questions. They took responsibility for their own learning rather than passively accepting their teacher's explanations. As a third step (proposing explanations and solutions), the teacher explained the concept based on students' answers by using some analogies. The teacher focused on students' misconceptions and tried to help them accommodate their cognitive structures. As a last step (taking actions), the teacher raised questions involving a new concept.

In the experimental group, social interaction was also emphasized and the teacher encouraged the students to work together, to explain what they were doing and reflect during the learning process. Students were guided to apply their existing ideas and prepare them to change them with the scientifically correct explanations by lowering the status of their initial conceptions.Students in the control group did not experience the same situation and there was only limited interaction between the teacher and the students. Meaningful learning occurs only when students are guided to integrate new learning within their existing cognitive structures in appropriate ways.

The results also indicated that students instructed by the constructivistic approach had more positive attitudes toward chemistry as a school subject than students taught by the traditionally designed chemistry instruction. Most students view chemistry as a difficult subject to learn and they try to avoid chemistry instruction in schools. But, students in the experimental group had significantly more positive attitudes towards chemistry instruction that focused on their ideas and encouraged them to reflect on relevant situations, apply their knowledge and share ideas with their peers. Well-designed activities should always take into consideration students' preconceptions and encourage them to reflect and explain phenomena.

REFERENCES

APPLETON, K. (1993). Using theory to guide practice: Teaching science from a constructivist perspective. *School Science and Mathematics, 93,* 269-274.

AUSUBEL, D. P. (1968). *Educational Psychology: A Cognitive View.* New York: Holt, Rinehart and Winston.

BEN-ZVI, R., EYLON, B. S. & SILBERSTEIN, J. (1987). Students' visualization of a chemical reaction. *Education in Chemistry, 24,* 117-120.

BIRK, J. P., & 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.

BOO, H., & WATSON, J. R. (2001). Progression in high school students (aged 16-18) conceptualizations about chemical reactions in solution. *Science Education, 85,* 568-585.

BROWN, D. E., & CLEMENT, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science, 18,* 237-261.

BUTTS, B., & SMITH, R. (1987). HSC chemistry students' understanding of the structure and properties of molecular and ionic compounds. *Research in Science Education, 17,* 192-201.

CAPRIO, M. W. (1994). Easing into constructivism, connecting meaningful learning with student experience. *Journal of College Science Teaching, 23,* 210-212.

CAREY, S., EVANS, R., HONDA, M., JAY E., & UNGER, C. (1989). An experiment is when you try it and see if it works: a study of grade seven students' understanding of the construction of scientific knowledge. *International Journal of Science Education, 11,* 514-529.

COLL, R. K., & TAYLOR, N. (2001). Alternative conceptions of chemical bonding held by upper secondary and tertiary students. *Research in Science and Technological Education, 19,* 171-191.

COLL, R. K., & TREAGUST, D. F. (2003). Investigation of secondary school, undergraduate and graduate learners' mental models of ionic bonding. *Journal of Research in Science Teaching, 40,* 464-486.

DRISCOLL, M. P., (1994). Psychology of Learning for Instruction. Allyn and Bacon: A Division of Paramount Publishing, Inc.

DRIVER, R., & OLDHAM, V. (1986). A constructivist approach to curriculum development in science. *Studies in Science Education, 13,* 105-122.

DRIVER, R., ASOKO, H., LEACH, J., MORTIMER, E. & SCOTT, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23(7),* 5-12.

DYKSTRA, D. I. JR., BOYLE, C. F. & MONORCH, I. A. (1992). Studying conceptual change in learning physics. *Science Education, 76,* 615 - 652.

DYKSTRA, D. (1992). Studying conceptual change. In R. Duit, F. Goldberg and H. Niedderer (Eds.) *Research in physics learning: Theoretical issues and empirical studies,* pp.40-58, Kiel. Germany: Institute for Science Education at the University of Kiel.

EBENEZER, J. V., & ZOLLER, U. (1993). Grade 10 students' perceptions of and attitudes toward science teaching and school science. *Journal of Research in Science Teaching, 30,* 175-186.

FREEDMAN, M. P. (1997). Relationship among laboratory instruction, attitude toward science and achievement in science knowledge. *Journal of Research in Science Teaching, 34,* 343-357.

GARNET, P. J. (1992). Conceptual difficulties experienced by senior high school students of electrochemistry. Electric circuits and oxidation -reduction equations. *Journal of Research in Science Teaching, 29,* 121 - 142.

GEBAN, Ö., AŞKAR, P., & ÖZKAN, İ. (1992). Effects of computer simulations and problem-solving approaches on high school students. *Journal of Educational Research, 86,* 5-10.

HARRISON, A. G. & TREAGUST, D. F. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple-model use in grade 11 chemistry. *Science Education, 84,* 352-381.

HARTY, H., BEALL, D., & SCHARMANN, L. (1985). Relationship between elementary school students' science achievement and their attitudes toward science, interest in science, reactive curiosity and scholastic aptitude. *School Science and*

Mathematics, 85, 472-479.

HESSE, J. J., & ANDERSON, W. C. (1992). Students' conceptions of chemical change *Journal of Research in Science Teaching 29,*277 - 299.

HEWSON, P. W. (1996). Teaching for conceptual change. In D. F. Treagust, R. Duit, & B. J. Fraser (Eds.), Improving Teaching and Learning in Science and Mathematics, pp. 131-140. New York, NY: Teachers College Press.

HILL, G. D., & ATWATER, M. M. (1995). Attitudes toward science of urban seventh grade life science students over time, and the relationship to future plans, family, teacher, curriculum, and school. *Urban Education, 30,* 71-94.

JONES, M. G., CARTER, G., & RUA, M. J. (2000). Exploring the development of conceptual ecologies: Communities of concepts related to convection and heat. *Journal of Research in Science Teaching, 37,* 139-159.

KOBALLA, JR. T.R. (1992). Persuasion and attitude change in science education. *Journal of Research in Science Teaching, 29,* 63-80.

LAZAROWITZ, S. M. R. (2002). Computer simulations in the high school: Students' cognitive stages, science process skills and academic achievement in microbiology. *International Journal of Science Education, 24,* 803-821.

LEE, V. E., & BURKAM, D. J. (1996). Gender differences in middle grade science achievement: Subject domain, ability and course emphasis. *Science Education, 80,* 613-650.

MAOZ, N., & RISHPON, M. (1990). Attitudes towards school science: A comparison of participants and non-participants in extracurricular activities. *School Science and Mathematics, 90,* 13-22.

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

NIAZ, M. (1995). Cognitive conflict as a teaching strategy in solving chemistry problems: a dialectic-constructivist perspective. *Journal of Research in Science Teaching, 32,* 959-970.

NICOLL, G. (2001). A report of undergraduates' bonding misconceptions. *International Journal of Science Education, 23,* 707-730.

OKEY, J. R., WISE, K. C., & BURNS, J. C. (1982). Integrated Process Skill Test-2. (available from Dr. James R. Okey, Department of Science Education, University of Georgia, Athens, GA, 30602).

OSMAN, M. E., & HANNIFIN, M. J. (1994). Effects of advance questioning and prior knowledge on science learning. *Journal of Educational Research, 88,* 5-13.

PARDO, J. Q., & SOLAZ-PATOLEZ, J. J. (1995). Students' and teachers' misapplication of Le Chatelier's principle: implications for teaching of chemical equilibrium. *Journal of Research in Science Teaching, 32,* 939 - 957.

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

PIAGET, J. (1950). *The Psychology of Intelligence.* New York: Harcout, Brace.

PINCTRICH, P. R., MARX, R. W., & BOYLE, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63,* 167-199.

POSNER, G.J., STRIKE, K. A., HEWSON, P. W., & GERTZOG, W. A. (1982). Accommodation of a scientific conception: toward theory of conceptual change. *Science Education, 66,* 211-227.

REIF, F., & LARKIN, J. (1991). Cognition in scientific and everyday domains: Comparison and learning implications. *Journal of Research in Science Teaching, 28,* 733-760.

RENSTROM, L., ANDERSON, B., & MORTON, F. (1990). Students' conceptions of matter. *Journal of Educational Psychology 82,* 555 - 569.

SIMPSON, R. D., & OLIVER, J. S. (1990). A summary of major influences on attitude toward and achievement in science among adolescent students. *Science Education, 74,* 1-18.

SMITH, L. E., BLAKESLEE, T. D., & ANDERSON, C. W. (1993). Teaching strategies associated with conceptual change learning in science. *Journal of Research in Science Teaching, 30,* 111-126.

STEFFE, P. L., & GALE, J. (1995). *Constructivism in Education.* New Jersey: Lawrence Erlbaum Associates, Inc.

STEPANS, J., DICE, S., & BEISWENGER, R. (1988). The effects of two instructional models in bringing about a conceptual change in the understanding of science concepts by prospective elementary teachers. *Science Education, 72,* 185-195.

STAVER, J. R., & LUMPE, A. T. (1995). Two investigations of students understanding of the mole concept and its use in problem solving. *Journal of Research in Science Teaching 32,* 177 - 193.

SUNGUR, S., TEKKAYA, C., & GEBAN, Ö. (2001). The contribution of conceptual change texts accompanied by concept mapping to students' understanding of the human circulatory system. *School Science and Mathematics, 101,* 91-101.

TABER, K. S. (1994). Misunderstanding the ionic bond. *Education in Chemistry, 31(4),* 100-103.

TABER, K. S. (1995). Development of student understanding: A case study of stability and liability in cognitive structure. *Research in Science and Technological Education, 13,* 89-99.

TABER, K. S. (2003). Mediating mental models of metals: acknowledging the priority of the learner's prior learning. *Science Education, 87,* 732-758.

TAN K. D., & TREAGUST D. F. (1999). Evaluating students' understanding of chemical bonding. *School Science Review, 81(294),* 75-83.

TEICHERT, M. A., & STACY, A. M. (2002). Promoting understanding of chemical bonding and spontaneity through student explanation and integration of ideas. *Journal of Research in Science Teaching, 39,* 464-496.

TYNJALA, P. (1998). Traditional studying for examination versus constructivist learning tasks: do learning outcomes differ? *Studies in Higher Education, 23,* 173-190.

TYSON, L. M., VENVILLE, G. J., HARRISON, A. G., & TREAGUST, D. F. (1997). A multidimensional framework for interpreting conceptual change events in the classroom, *Science Education, 81,* 387 - 404.

VALANIDES, N. (2000). Primary student teachers'understanding of the particulate nature of matter and its transformations during dissolving. Chemistry

Education:Research And Practice In Europe (CERAPIE), 1(2), 249-262. (http://www.uoi.gr/conf_sem/cerapie)

VALANIDES, N. (2000). Primary student teachers' understanding of the process and effects of distillation. *Chemistry Education:Research And Practice In Europe (CERAPIE)*, *1*(3), 355-364. (http://www.uoi.gr/conf_sem/cerapie)

VALANIDES, N., NICOLAIDOU, A, & EILKS, I. (2003). Twelfth-grade Students' Understandings of Oxidation and Combustion: Using Action Research to Improve Teachers' Practical Knowledge and Teaching Practice. Journal of Science & Technology Education, 21(2), 59-75.

YAGER, R. E. (1991). The constructivist-learning model: Towards real reform in science education. *The Science Teacher, September*, 53-57.