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# The Effectiveness of Conceptual Change Texts in Remediating High School Students' Alternative Conceptions Concerning Chemical Equilibrium

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This study investigated the effectiveness of conceptual change texts in remediating high school students' alternative conceptions concerning chemical equilibrium. A quasi-experimental design was used in this study. The subjects for this study consisted of a total 78 tenth-grade students, 38 of them in the experimental group and 40 of them in the control group. A questionnaire, the Alternative Conceptions about Chemical Equilibrium Test (ACCET), was developed and administered to students as a pretest and posttest. While the experimental group received a conceptual change text instruction, the control group received a traditional style instruction. The results of the study indicated that the students in the experimental group showed significantly greater levels of achievement than the students in the control group. Moreover, in both groups the percentages of students' alternative conceptions decreased in the however the experimental group did better than the control group.

Key words: chemistry education, chemical equilibrium, conceptual change text, alternative conception

## Introduction

One of the main purposes of every chemistry instructor is, of course, to help students understand scientific ideas and chemical phenomena. Research has shown that students often construct their own theories about how the natural world works and come to school with varying experiences with, ideas about, and explanations of the natural world, but their personal theories (explanations) are frequently contrary to those of scientists' (Osborne & Freyberg, 1985). In the literature, such student ideas have been referred to variously as alternative conceptions, misconceptions, preconceptions, naïve conceptions, and children's science (Özmen, 2004). Throughout this article, the term alternative conceptions will be used to refer to students' conceptions that are different from scientifically accepted ones.

Alternative conceptions may arise as a result of a variety of contacts students make with the physical and social world or as a result of personal experiences; interactions with teachers, other people, or through the media; traditional instructional language; mismatches between teacher and student knowledge of science; the abstract nature of science concepts; and textbooks portrayals (Griffiths & Preston, 1992; Soyibo, 1995; Pedrosa & Dias, 2000). It is well known that such student beliefs influence how students learn new scientific knowledge and play an essential role in subsequent learning. Additionally, these are persistent, stable, resistant to change, at least by traditional teaching methods, and difficult to alter even by specific instruction designed to address them (Arnaudin & Mintzes, 1985; BouJaoude, 1991). In the literature, many studies

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have investigated students' understanding of chemistry concepts such as chemical bonding (Taber, 1998), acids and bases (Ross & Munby, 1991), the particulate nature of matter (De Vos & Verdonk, 1996), and atoms and molecules (Griffiths & Preston, 1992), and chemical equilibrium (Hackling & Garnett, 1985). These studies show that some students retain many alternative conceptions and students face several cognitive conflicts when dealing with chemical concepts. This makes it more important to alter students' alternative conceptions of scientific concepts than just identifying them. When the above research works are examined, it is seen that many of them were designed to determine students' alternative conceptions. Recently, studies have turned towards the determination of the effect of alternative teaching approaches on students' learning and altering their alternative conceptions to scientific ones. Because traditional teaching strategies are ineffective in helping students develop a complete understanding of the abstract concepts to build correct conceptions, to alleviate alternative conceptions, and to promote conceptual change (Westbrook & Marek, 1991), a variety of successful remediation techniques have been documented in the literature. Utilizing concept mapping, animations, analogy, computer-assistant simulations, conceptual change strategies, and laboratory activities are among those methods identified (Dagher, 1994; Mason, 1994; Chambers & Andre, 1997; Huddle, White, & Rogers, 2000).

Learning about science in a meaningful way involves realizing, reorganizing or replacing existing conceptions to accommodate new ideas (Smith & Blakeslee, 1993). According to constructivist theory, learning can be viewed as a process of conceptual change. Conceptual change, within this realm, implies that a learner actively replaces existing prescientific conceptions with scientifically acceptable explanations as new propositional linkages are formed in her/his conceptual framework. The conceptual change approach to science instruction represents an alternative approach designed to encourage students to alter preconceptions and is based on Piaget's notions of assimilation, accommodation, and disequilibrium (Wang & Andre, 1991). Posner, Strike, Hewson, and Gertzog (1982) adapted Piagetian theory into an instructional strategy and provided an explanation for how conceptual change might occur. They suggested that accommodation will begin when there is dissatisfaction with an existing conception; then it will proceed as the student considers a new conception to be more intelligible, plausible, and fruitful. In another words, the belief that new knowledge should be intelligible, plausible, and fruitful plays a key role in the process of conceptual change. Among various instructional methods, conceptual change strategy can be used for this purpose. Another conceptual change strategy involves using conceptual change texts. These texts are designed to change students' alternative conceptions and focus on strategies to promote conceptual change by challenging students' alternative conceptions, producing dissatisfaction, followed by a correct explanation which is both understandable and plausible to the students. In these texts, the identified alternative conceptions of the students are given first, alternative conceptions are activated by presenting them with situations designed to elicit a prediction based on them and alternative conceptions are challenged by introducing common alternative conceptions followed by evidence that they are wrong. Finally, students are informed of the correct explanations supported by examples.

In the science education literature, there is an abundance of studies related to utilization of conceptual change texts (Wang & Andre, 1991; Hynd, Mcwhorter, Phares, & Suttles, 1994; Chambers & Andre, 1997; Mikkila, 2001; Yürük & Geban, 2001; Cakir, Uzuntiryaki, & Geban, 2002; Palmer, 2003; Tekkaya, 2003; Canpolat, Pinarbasi, Bayrakceken, & Geban, 2006; Baser & Geban, 2007a; Baser & Geban, 2007b). Wang and Andre (1991) and Chambers and Andre (1997) investigated the effect of conceptual change texts on students' understanding and showed that subjects who received a conceptual change text instruction significantly improved their performance in their understanding of electricity concepts as compared to traditional texts. In another study, Hynd et al. (1994) reported the effectiveness of conceptual change texts on bringing about conceptual change and promoting meaningful learning in students regarding Newton's laws of motion. Regarding biological concepts, Mikkila (2001) and Palmer (2003) demonstrated the effectiveness of conceptual change text instruction on students' understanding of photosynthesis, human circulatory system, and ecological roles, respectively. In addition, Tekkaya (2003) investigated the effectiveness of combining conceptual change texts and concept mapping strategy on students' understanding of diffusion and osmosis. The results indicated that there was a statistically significant difference between the experimental and control groups in the favor of the experimental group after treatment. In chemistry education, Yürük and Geban (2001) and Cakir, Uzuntiryaki, and Geban (2002) reported that instruction based on conceptual change texts resulted in a significantly better acquisition of scientific conceptions related to electrochemical cells, and acids and bases as compared to a traditional style instruction. In addition, Canpolat et al. (2006) investigated the effect of a conceptual change approach over traditional instruction on students' understanding of chemical equilibrium concepts. The results showed that the students in experimental group performed better than the control group.

In high school chemistry curricula, the topic of chemical equilibrium occupies a central place. Although there are several concepts about which students have difficulty, chemical equilibrium is considered to be one of the most difficult and important topics in general chemistry curriculum (Bergquist & Heikkinen, 1990; Garnett, Garnett, & Hackling, 1995; Tyson, Treagust, & Bucat, 1999; Solomonidou & Stavridou, 2001; Piquette & Heikkinen, 2005), owing to its abstract character and its demand of a mastery of a large number of subordinate concepts (Quilez-Pardo & Solaz-Portoles, 1995) and the essential role in developing an understanding in other areas of chemistry such as acid-base behavior, solubility, and oxidation-reduction reactions (Voska & Heikkinen, 2000). Moreover, Bilgin (2006) states that chemical equilibrium presents particular opportunities for alternative conceptions because students are passing examinations and continuing into higher years of study with little understanding of this concept. The reason for this is that the chemical equilibrium concept is one of the most difficult concepts to understand. Starting from this perspective, there has been considerable interest in discovering students' alternative conceptions and the reasons why many students have great difficulty in successfully developing a scientifically accepted understanding of chemical equilibrium for the last two decades. On the other hand, there is a lack of studies that focus on determining the effect of different instructional approaches in understanding chemical equilibrium. Recently, for example, Solomonidou and Stavridou (2001) and Saricayir, Sahin, and Uce (2006) investigated the effect of computer animations on students' understanding of chemical equilibrium. In addition, Akkus, Kadayifci, Atasoy, and Geban (2003) investigated the effectiveness of instruction based on the constructivist approach on understanding chemical equilibrium. However, these studies are quantitatively insufficient. Even in the literature itself, there appears to be only a single study that directly focuses on the investigation of the effect of conceptual change texts on students' understanding of chemical equilibrium (Canpolat et al., 2006). Therefore, the number of different studies related to effectiveness of the conceptual change texts on different conceptual areas and alternative conceptions on chemical equilibrium should be increased. With this in mind, a major aim of this study was determining of the effects on instruction based on conceptual change texts on students' understanding and alternative conceptions and comparing the results with related literature.

## Method

### *Research Design*

A quasi-experimental design was used in this study. Quasi-experimental design is a research design in which participants are not randomly assigned to the groups, instead, there are naturally occurring groups or groups to which participants are assigned for reason(s) other than randomizing the sample (Judd, Smith, & Kidder, 1991). One control and one experimental group were used in the study. The study utilized "a pretest-posttest nonequivalent control group design" (Robson, 1998). Each group was given both a pretest and a posttest, measuring the dependent variable both before and after exposure to the independent variable. The research design can be represented as follows:

| | Pretest | Intervention | Posttest |
|---|---|---|---|
| EG | T | $X_1$ | T |
| CG | T | $X_2$ | T |

The broken line separating the two groups indicates that people were not randomly assigned to the groups. EG represents the experimental group that was taught using Conceptual Change Texts ($X_1$), and CG represents the control group that was taught by a traditional teacher-centered approach ($X_2$). T represents the ACCEQ.

***Participants***

The subjects for this study consisted of a total of 78 tenth-grade students (43 boys, 35 girls, with an average age of 16.4 years). One class (n = 38, 21 boys and 17 girls) was assigned as the experimental group and the other (n = 40, 22 boys and 18 girls) as the control group. The school has about 780 students in total and they come from similar socio-economic backgrounds. Two of the five chemistry teachers in the school volunteered to participate in this study. One of the teachers and his class was randomly chosen as the control group, and the other teacher and his class became the experimental group. The experimental group teacher had 12 years of experience teaching chemistry, and the control group teacher had 15 years of experience. Based on this, we can say that teachers had a comparable background and level of experience in teaching chemistry. The chemistry course in the school consists of five 45-minute periods per week; it includes three lectures and two laboratory sessions. The experimental group teacher holds both undergraduate and masters degrees in teaching chemistry. The researcher and the teacher discussed the most appropriate ways of using conceptual change texts and the teacher was informed of this by the researcher prior to the study.

***Instrumentation***

The Alternative Conceptions about Chemical Equilibrium Test (ACCET) was developed and used to determine students' alternative conceptions and learning difficulties on the target concept in this study.

***Development of the Alternative Conceptions about Chemical Equilibrium Test (ACCET)***

The (ACCET) includes 20 multiple-choice questions. In the development process, six of the questions were adopted from the literature (Tyson, Treagust, & Bucat, 1999; Voska & Heikkinen, 2000; Piquette & Heikkinen, 2005) with minor revisions and the format was redesigned according to the adopted multiple-choice format. The rest of the questions were developed by the researcher.

Although there already exist such tests (e.g. Akkus et al., 2003), these tests contain different conceptual areas and different types of questions, such as two tier multiple-choice, multiple-choice with three, four, five or more distracters, etc. The ACCET contains four major conceptual areas. These areas were: (a) the approach to equilibrium, (b) the application of Le Chatelier's principle, (c) the constancy of the equilibrium constant and (d) heterogeneous equilibrium. The areas evaluated in the tests are presented below.

In addition, in the ACCET, multiple-choice questions covered by the test, composed of four distractors and alternative conceptions, were gathered from the related literature and were reflected by the distractors of each test items. In other words, the items in the test included one correct answer and four distracters that reflected students' probable misconceptions reported in the related literature. Some examples of the test question are presented in Figure 1.

Four assistant professors of chemistry and an associate professor of chemistry who teaches chemistry at the Department of Science Education reviewed the instrument to determine its content validity. They agreed that each item is suitable for the aim of the studies and related to previously described major conceptual areas. The pilot study of this test was applied to 42 tenth-grade students who had studied the concept of chemical equilibrium before and some modifications were made based on this before the main administration. The reliability of the test was estimated to be 0.71 using the Sperman-Brown formula. The reliability of the test was calculated by using a software package programme, SPSS 10.0. A correct answer is given 1 point which makes the maximum possible score from the

Table 1
*The Characteristics of the Alternative Conceptions about Chemical Equilibrium Test (ACCET)*

| | |
|---|---|
| Areas evaluated | The approach to equilibrium: items 3, 7, 8, 10, 15, and 17<br>The application of Le Chatelier's principle: items 4, 6, 12, 13, 16 and 20<br>The constancy of the equilibrium constant: items 1, 5, 11, 14 and 18<br>Heterogeneous equilibrium: items 2, 9 and 19 |

**1.** Limestone decomposes to form lime and carbon dioxide as follow: $\mathbf{CaCO_{3\,(s)} \rightleftharpoons CaO_{\,(s)} + CO_{2(g)}}$ What can we say about the equilibrium shift after removing some solid $CaCO_3$ from the equilibrium mixture?

a. System increases the amount of $CaCO_3$ and new equilibrium establishes
b. Because $CaCO_3$ is solid, removing it does not affect the equilibrium
c. $CO_2$ and CaO react to form more $CaCO_3$ according to Le Chatelier's principle
d. The amount of removing solid $CaCO_3$ is not known

**2.** Carbon monoxide and hydrogen react according to the following equation. $\mathbf{CO_{\,(g)} + 3H_{2(g)} \rightleftharpoons CH_{4\,(g)} + H_2O_{\,(g)}}$. When 0.02 M CO and 0.03 M $H_2$ are introduced into a vessel at 800 K and allow coming to equilibrium, what can we say about the rate of reverse and forward reactions at equilibrium?

a. Forward reaction goes to completion before the reverse reaction starts
b. The rates of the forward and reverse reactions are equal when the system reaches to the equilibrium
c. As time passes, the concentrations of products increase
d. At the beginning, the concentrations of the reactants are greater than the concentrations of products

**3.** In the first step of the Ostwald process for the synthesis of nitric acid, ammonia is oxidized to nitric oxide by the reaction; $\mathbf{4NH_{3\,(g)} + 5O_{2\,(g)} \rightleftharpoons 4NO_{\,(g)} + 6H_2O_{\,(g)}}$ , $\Delta H = -905.6$ kJ. How does the equilibrium constant vary with an increase in temperature?

a. An increase in temperature always increases the numerical value of $K_{eq}$
b. Because the reaction is exothermic, the concentration of product increases
c. The equilibrium shift to the left with an increase in temperature
d. Whether the reaction is endothermic or exothermic do not affect the $K_{eq}$

*Figure 1.* Example questions used in the ACCET

test 20 points.

***Texts***

The texts used in this study were constructed by a group of chemistry student teachers under the researcher's supervision. Five such texts were prepared by taking into consideration students' alternative conceptions determined with the ACCET and gathered from the literature. According to constructivist learning models, open-ended questions could be asked of students to initiate learning. In the text, such questions were presented to students at the top of the texts. The purpose of this question was to activate students' alternative conceptions. In each of the texts, the topics were introduced by such questions and students' possible answers that are not scientifically accepted were mentioned directly. In this way, students are expected to be dissatisfied with their present conceptions. Therefore, the texts developed for this study are similar to the ones developed and used before in the literature (Tekkaya, 2003; Canpolat et al., 2006). In the literature, examples and figures were used in the texts with the intention of further helping students understand the scientific concept and realize the limitations of their own ideas. In this study, examples, equations and numerical values were used for this purpose in a way different from the manner indicated in the literature. The conceptual areas covered by the conceptual change texts were; the approach to equilibrium, the application of Le Chatelier's principle, the constancy of the equilibrium constant and heterogeneous equilibrium. Each text aims to remediate the alternative conceptions identified previously and which were related to these conceptual areas. In each of the texts, students were introduced to questions and their possible answers that may include alternative conceptions held by the students. Following the prediction phase, the students were presented with common alternative conceptions along with evidence countering these alternative conceptions and then discussed in the texts. In

***The Approach to Equilibrium***

***Introduction:*** When does a system reach equilibrium?

Students generally believe that *when there are equal concentrations of substances on both sides of an equation, chemical equilibrium is reached.* **This is incorrect**. While explaining the equilibrium, we can say that when the rates of forward and reverse reactions become equal, dynamic equilibrium is established and there are no further changes in concentrations at equilibrium. It is likely that one could interpret this statement by saying that the concentration of reactants and products become equal at equilibrium. However, on the other hand, it must not be forgotten that if the concentrations become equal on both sides of the equation, the numerical value of the equilibrium constant, ($K_{eq}$), is always equal to 1 when the total stoichiometric coefficients of the reactants equal the coefficients of the products and the numerical values of the equilibrium constants of forward and reverse reactions must be equal. However, we know that the values of the equilibrium constants of forward and reverse reactions are reciprocals of each other. For example, while the equilibrium constant for the formation of HI, $H_2(g) + I_2(g) \leftrightarrows 2HI(g)$, is $K_{eq} = 54.5$, the constant for the reverse reaction, $2HI(g) \leftrightarrows H_2(g) + I_2(g)$, is $K_{eq}' = 1/K_{eq} = 1.83x10^{-2}$. If the equilibrium concentrations are equal, equilibrium constants must also be equal. Moreover, we know that $K_{eq}$ takes different values for the same reaction, depending on the temperature. It must not be forgotten that for a particular reaction at a specific temperature, the ratio of concentrations between reactants and products will always have the same value. This is because it does not depend on the amounts of reactants and products mixed together initially, $K_{eq}$ remains the same i.e., the concentrations themselves may vary, but the ratios between the concentrations in a given situation do not. **As a result, when the rate of forward reaction becomes the rate of reverse reaction, chemical equilibrium is reached**.

*Figure 2.* An example of a portion of the conceptual change texts designed to challenge the alternative conception

this way, students were expected to be dissatisfied with their current conception. Finally, the students were informed of the correct scientific explanations supported by examples. An example of a portion of the conceptual change texts designed to challenge the alternative conception is as follows; "*when there are equal concentrations of substances on both sides of an equation, chemical equilibrium has been reached"* This is presented in Figure 2.

***Procedure***

There were two groups of students in this study, one experimental and one control group. The two groups spent an equal time studying the unit. During this period, each group was provided with the same materials except in the of the conceptual change texts in the experimental group. The same topics related to chemical equilibrium concepts which are the approach to equilibrium, the application of Le Chatelier's principle, the constancy of the equilibrium constant, the heterogeneous equilibrium. These were covered for both experimental and control groups.

The study was conducted in two phases. In the first phase, the ACCET was administered to both groups of students as a pretest to identify students' conceptual understanding of chemical equilibrium before the treatment and students' ideas were determined and then used to prepare the conceptual change texts. In the second phase, the treatment was conducted. In the treatment process, the traditional instruction approach used for the control group was based on the teacher providing explanations of the concepts related to chemical equilibrium in a lecture type format, and using the textbook for examples and illustrations. On the other hand, the experimental group was given conceptual change texts instruction, designed to remediate students' alternative conceptions about the notion of chemical equilibrium. In the treatment process, conceptual change texts were distributed to students after presenting each concept and each of the students was asked to read the texts silently and carefully in class. The existing conceptions on the part of the students were expected to be activated in relation to the chemical equilibrium concept by asking them questions. Following this, the conceptual change texts were discussed with the students; and common alternative conceptions were emphasized. Following this, plausible, fruitful, and scientifically correct concepts and explanations were provided to the students so as to give them an opportunity to develop scientifically accepted conceptions. The study was conducted over a four-week period and both groups received regular instruction on chemical equilibrium during the course of the experiment. At the end of the study, the ACCET was administered to both groups of students as a posttest.

***Data Analysis***

In the analysis of the ACCET, firstly, the total scores of each student in both groups and then the mean score of each group were computed. The mean scores of the groups were compared by using an independent *t* test for both the pretests and posttests.

## Results and Discussion

The ACCET was administered to both group of students before the treatment as a pretest and no statistically significant difference between the average scores was found ($t$ = 0.44, $df$= 76, $p$>0.05). This indicates that students in both groups were similar with respect to their level of achievement in so far as it applied to the notion of chemical equilibrium. When the posttest scores were compared by means of the *t* test, it was found that a statistically significant difference between the experimental group (M = 14.58, SD = 4.67) and control group (M = 11.18, SD = 3.52) mean scores existed in favor of the experimental group. Table 2 shows the *t* test results, comparing the overall differences in both groups with respect to the posttest results.

This finding shows that students in the experimental group exhibited significantly higher performance levels than students in the control group. The participants in the experimental group made substantial gains in their understanding of the nature of chemical equilibrium. In the control group, the instructor did not try to identify students' alternative conceptions in advance and hence potentially ignored any existing alternative conceptions during instruction. For this reason, many of the students still carried their alternative conceptions or developed new ones after the instruction. On the other hand, the experimental group was given conceptual change texts instruction, designed to remediate students' alternative conceptions about this concept. In the course of this process, the instructor primarily had two aims: i) to remediate current alternative conceptions and ii) to prevent the development of new ones. This caused a decrease in the students' alternative conceptions in the posttest. However, although a significant difference was found between the groups in the posttest, none of the students in the experimental group fully remediated their alternative conceptions about chemical equilibrium. The persistent existence of some alternative conceptions in the experimental group students after the instruction is evidence for this. The reason for this may be the effect of the previously taught concept and students' deep seated understandings of the chemistry topics related to chemical equilibrium. This result support the notion that alternative conceptions are very stable, since it is not easy to replace them with scientific conceptions (Novak, 2002) even in the case where the learning environment and application are well-designed. For example, Banerjee and Power (1991) reported that about 30% of students still held alternative conceptions about chemical equilibrium after instruction, despite using three modules on chemical equilibrium developed as a resource. These examples emphasize the fact that the correction of alternative conceptions is an extremely difficult and challenging task.

The main aim of this study was to determine the effectiveness of conceptual change texts in remediating students' alternative conceptions. Therefore, the number and frequency of students' alternative conceptions in both the pretest and posttest were determined by using the ACCET. Fifteen alternative conceptions were identified and these

Table 2

*Comparison of the Experimental and Control Groups for overall Differences in the ACCET afterTtreatment*

| Measures | Experimental Group | | | Control Group | | | | |
|---|---|---|---|---|---|---|---|---|
| | *N* | Mean | *SD* | *N* | Mean | *SD* | *t* | *p* |
| ACCEQ | 38 | 14. 58 | 4.67 | 40 | 11.18 | 3.52 | 3.65 | 0,001 |

were grouped under the headings of the application of Le Chatelier's principle, the constancy of the equilibrium constant and the heterogeneous equilibrium. The results of the tests are presented in Table 3.

As can be seen from Table 3, students in both groups held almost the same alternative conceptions in pretests and at about the same percentages. In the literature, several studies reported similar types and levels of student alternative conceptions (e.g. Hackling & Garnett, 1985; Bergquist & Heikkinen, 1990; Quilez-Pardo & Solaz-Portoles, 1995). The percentages of the experimental group students' alternative conceptions in pretests ranged from 21% to 71%, and those of the control group students' ranged from 23% to 73%. Table 3 shows that there is a significant difference between the percentages of alternative conceptions held by students in the experimental and control

Table 3
*The Percentages of Students' Alternative Conceptions as Determined in Pretest and Posttest*

| | Alternative Conceptions | Experimental Group *N*=38 | | Control Group *N*=40 | |
|---|---|---|---|---|---|
| | | Pretest (%) | Posttest (%) | Pretest (%) | Posttest (%) |
| *Approach to equilibrium* | • Forward reaction goes to completion before the reverse reaction starts | 71 | 8 | 68 | 35 |
| | • When there are equal concentrations of substances on both sides of an equation, chemical equilibrium is reached | 68 | 2 | 60 | 40 |
| | • The rate of forward reaction is greater than the reverse reaction rate | 55 | 13 | 65 | 33 |
| | • Equilibrium reactions continue until all of the reactants run out | 63 | 5 | 70 | 43 |
| | • At equilibrium, no reaction occurs | 63 | 0 | 60 | 13 |
| *Application of Le Chatelier's principle* | • When some matter is added to equilibrium mixture, equilibrium will shift to the side of addition | 38 | 3 | 35 | 10 |
| | • When the temperature is changed, the type of reaction (endothermic or exothermic) does not affect the direction of the equilibrium shift | 55 | 3 | 58 | 8 |
| | • When the temperature is increased, more products are formed | 66 | 13 | 73 | 40 |
| *Constancy of equilibrium constant* | • An increase in temperature always increases the numerical value of $K_{eq}$ | 68 | 5 | 60 | 28 |
| | • Equilibrium constant, $K_{eq}$, will decrease with increasing temperature in an endothermic reaction | 26 | 0 | 25 | 8 |
| | • Equilibrium constant, $K_{eq}$, will increase with increasing temperature in an exothermic reaction | 32 | 0 | 28 | 8 |
| | • When more products are added to an equilibrium system at constant temperature, $K_{eq}$ will increase | 53 | 5 | 73 | 48 |
| | • The numerical value of $K_{eq}$ changes with the amounts of reactants or products present | 63 | 8 | 63 | 38 |
| *Heterogeneous equilibrium* | • Le Chatelier's principle can be applied in all systems, including heterogeneous equilibrium systems | 21 | 0 | 23 | 3 |
| | • Concentrations of solids are included in the equilibrium constant | 24 | 0 | 30 | 3 |

groups after treatment. These results show that conceptual change texts helped students to change their alternative conceptions for scientifically accepted ones.

One of the most common alternative conceptions held by both groups of students was that "*forward reaction goes to completion before the reverse reaction starts*". 71% of the experimental group and 68% control group held this alternative conception. A similar alternative conception had been reported by Hackling and Garnett (1985), and Banerjee (1991). As seen in Table 3, in both groups, the percentages of this alternative conception decreased on the posttest, but the experimental group did better than the control group, 8% in experimental group and 35% in control group. The conceptual change text related to this alternative conception was probably the reason for the better scores of the experimental group's students. In this text, it was stated that in a reversible reaction, only collisions between reactant molecules occur, meaning the forward reaction is relatively fast at time zero. However, at the very beginning of the reaction, there are no products, which mean that the product concentration is zero. Therefore, the rate of reverse reaction is zero and the rate of forward reaction is greater than the reverse reaction at the beginning. However, as the forward reaction progresses and products form, the product concentration increases and the speed of the reverse reaction begins to increase. As time passes, while the forward reaction slows down, the reverse reaction speeds up and eventually the two reaction rates become equal. This explanation enabled the experimental group students to be more successful than the control group students in the posttests. Canpolat et al. (2006) removed this alternative conception completely in their study.

Another alternative conception was that "*when there are equal concentrations of substances on both sides of an equation, chemical equilibrium is reached*". This was held by 68% of the experimental group and 60% of the control group students in the pretest. These students thought that concentrations of reactants and products become equal at equilibrium. Hackling and Garnett (1985), and Huddle and Pillay (1996) had reported a similar alternative conception. While explaining the equilibrium, we can say that when the rates of forward and reverse reactions become equal, dynamic equilibrium is established and there are no further changes in concentrations at equilibrium (Olmsted & Williams, 1994). It is likely that students interpret this statement to mean that the concentration of reactants and products become equal at equilibrium. The conceptual change text presented in Figure 2 explained this situation to the students in the experimental group. As seen in Figure 2, in this text, it was explained to students that if the concentrations become equal on both sides of the equation, the numerical value of the equilibrium constant, ($K_{eq}$), always is equal to 1 when the total stoichiometric coefficients of the reactants equal the coefficients of the products; and therefore, the numerical values of the equilibrium constants of forward and reverse reactions must be equal. However, we know that the values of the equilibrium constants of forward and reverse reactions are reciprocals of each other. This explanation allowed students to think about their prior knowledge and helped them revise their misunderstandings and deal with their alternative conceptions. Based on this, while 40% of the students in the control group had this alternative conception, only 2% of the students in the experimental group exhibited alternative conceptions in posttests. The results of Canpolat et al. (2006)'s study were similar, in so far as they related to this alternative conceptions.

Another way to disturb equilibrium was to change the temperature. Two alternative conceptions related to the effects of temperature change on a system which is at equilibrium were as follows. Firstly, "*when the temperature is changed, whether the reaction is endothermic or exothermic do not affect the direction of the equilibrium shift*". This was held by 55% of the students in the experimental group and 58% of the students in the control group. Secondly, *when the temperature is increased, more products form,* a conception which was held by 66% of the students in the experimental group and 73% of the students in the control group. Voska and Heikkinen (2000) reported a similar alternative conception that when the temperature is changed, the direction of an equilibrium shift can be predicted without knowing whether the reaction is endothermic or exothermic. These alternative conceptions were also considered in designing the conceptual change texts. Reactions that release energy into the surroundings as they occur are called exothermic and reactions that absorb energy from their surroundings are called endothermic. While the heat is added to the reactants' side in an endothermic reaction, in exothermic reactions, heat is added to the products' side. When heat is a product, the addition of heat which must occur as the temperature is raised, drives the equilibrium backward, while if heat is a reactant then the addition of heat drives the equilibrium forward. Remembering Le Chatelier's principle, we can say that if the temperature is increased, the equilibrium will shift to the products' side in an endothermic reaction. Conversely, if the temperature is increased, the equilibrium will shift to the reactants' side in an exothermic reaction. As a result of this, we can say that the effect of the temperature changes on the equilibrium depends on whether the reaction is endothermic or exothermic. Based on this, when the temperature is increased, more products or more reactants are formed whether the reaction is endothermic or exothermic. The percentages of these alternative conceptions in both groups of students decreased in the posttest, but the experimental group did better than the control group based on the explanations in conceptual change texts.

As another alternative conception, students in both group thought that "*the numerical value of* $K_{eq}$ *changes with amounts present of reactants or products*", a notion which was held 63% of the students in both groups. In the conceptual change texts, students said that at a given temperature, the equilibrium constant has only one value and this value is independent of the initial conditions. This means that the numerical value of $K_{eq}$ does not change with the amounts of reactants or products. While 38% of the students in the control group had this alternative conception, only 8% of the students in the experimental group still held it in posttests. In addition, the students also said that the value of the equilibrium constant only changes with temperature and reactants or products in addition to the equilibrium does not change the numerical value of the equilibrium constant. The view that "*when more products are added to equilibrium system at constant temperature,* $K_{eq}$ *will increase*", a view which held was held by 53% of the students in the experimental group and 73% of the students in the control group, was also altered in this way and only 5% of the experimental group students held this views while 48% of the students in the control group still held it in posttests.

Another prevalent alternative conception among students in both groups was that "*an increase in temperature always increases the numerical value of* $K_{eq}$", an idea which was held by 68% of the students in the experimental group and 60% of the students in the control group in pretests. Similar alternative conceptions were also reported in the related literature (Hackling & Garnett, 1985; Voska & Heikkinen, 2000). In the conceptual change texts, we considered this alternative conception and explained to the students that they should primarily remember that change in the numerical value of the equilibrium constant with temperature depends on whether the reaction is endothermic or exothermic. In addition, the equilibrium constant of an exothermic reaction decreases with increasing temperature, whereas the equilibrium constant of an endothermic reaction increases with increasing temperature. We can explain this behavior thermodynamically. In order to show how $ln(K_{eq})$ depends on $\Delta H°$, $\Delta S°$, and $T$, we can use the equation $ln(K_{eq}) = -\Delta H°/RT + \Delta S°/R$. An exothermic reaction has a negative $\Delta H°$, making the first term on the right of the equation positive. As $T$ increases, this term decreases, causing $K_{eq}$ to decrease. An endothermic reaction, in contrast, has a positive $\Delta H°$, making the first term on the right of the equation negative. As $T$ increases, this term becomes less negative, causing $K_{eq}$ to increase. With this way, we managed to reduce the percentage of the students who held this alternative conception in the experimental group from 68% to 5% in the posttests.

The students in the experimental group had completely corrected the following alternative conceptions in posttests: *"At equilibrium, no reaction occurs", "Equilibrium constant,* $K_{eq}$*, will decrease with increasing temperature in an endothermic reaction", "Equilibrium constant,* $K_{eq}$*, will increase with increasing temperature in an exothermic reaction", "Le Chatelier's principle can be applied in all systems, including heterogeneous equilibrium systems", "Concentrations of solids are included in the equilibrium constant".* On the other hand, students in the control group did not manage to completely correct any of their alternative conceptions. These results show the positive effects of the conceptual change texts oriented instruction in remediating the students' alternative conceptions.

## Conclusion and Implications

This study investigated the effectiveness of conceptual change texts in remediating high school students' alternative conceptions concerning the notion of chemical equilibrium. On the one hand, while the results of the study show that conceptual change texts based instruction was more successful in remediating students' alternative conceptions about chemical equilibrium than traditional instruction. On the other hand, the results also show that traditional teaching strategies are ineffective in helping students develop a complete understanding of abstract concepts such as chemical equilibrium to build correct conceptions, with the ultimate aim of alleviating alternative conceptions, and to promote conceptual change. When we look at the difference in instruction in both groups, we see that the conceptual change approach explicitly dealt with students' alternative conceptions, while the traditional approach did not. It is well known that traditional teaching strategies provide conceptual information to the students who learn the material, memorize it and reproduce it on the day of examination (Khalid, 2003). In regards to conceptual change strategies, emphasis is given to students' alternative conceptions and remedying them with scientific ones. In other words, the basic rationale in designing the conceptual change texts is to consider the students' alternative conceptions. Research findings seem to indicate that students' alternative conceptions in learning chemistry concepts are due in part to the teachers' lack of knowledge regarding students' prior understanding and knowledge of the very concepts being studied (Krishnan & Howe, 1994). One of the most fruitful outcomes of the studies on students' alternative conceptions is to alert teachers to students' difficulties in conceptualizing scientific knowledge and hence suggest more effective strategies for improving classroom instruction. The results of this study show that conceptual change texts may be an effective strategy for improving instruction and remedying students' alternative conceptions. The data gathered from the available literature also supports this view (Chambers & Andre, 1997; Mikkila, 2001; Tekkaya, 2003; Canpolat et al., 2006; Baser & Geban, 2007a; Baser & Geban, 2007b). In particular, the findings of Canpolat et al., (2006)'s are essentially parallel to this study. On the other hand, the results also show that some students in both groups still have alternative conceptions even after the instruction. This is evidence that the use of conceptual change texts by themselves may not be sufficient to remediate students' alternative conceptions. In the available literature, different techniques were used helping students to understand scientific concepts. For example, concept mapping, concrete examples, analogies, simulations, demonstrations, computer animations and figures are some of commonly used methods (Zietsman & Hewson, 1986; Harrison & Buckley, 2000; Huddle, White, & Rogers, 2000; Tekkaya, 2003; Solomonidou & Stavridou, 2001; Canpolat et al., 2006; Saricayir, Sahin, & Uce, 2006). Some of these techniques such as analogies, figures, computer animations, and simulations may be combined or accompanied with conceptual change text to increase the effectiveness of the instruction in this study. This is one of the lessons which we can take away with us from this study. Conceptual change texts combined or accompanied with analogies, models, demonstrations or computer animations can provide students with an opportunity to better understand and remediate their alternative conceptions about the notion of chemical equilibrium. For example, some of the alternative conceptions determined in this study were also determined by Canpolat et al. (2006) and they also sought to remedy these alternative conceptions. When the results of this study are compared to theirs, it seems that their treatment used in the experimental group was more successful. For example, students in both studies shared the alternative conceptions *the forward reaction goes to completion before the reverse reaction commences.* However, while the students in their sample did not hold these alternative conceptions in the posttest, the students in this study continued to hold this alternative conception at the ratio of 8%. It seems clear to this researcher at least that this result can be used to explain such a rationale reality. They used models and demonstrations in addition to conceptual change texts in ways different to this study.

Finally, some of the alternative conceptions about chemical equilibrium are simply remedied in different studies, while the others are deeply seated. Therefore, new techniques that are geared specifically at remedying these deeply rooted beliefs should be developed and tested in further studies.

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