Using analogies to prevent misconceptions about chemical equilibrium

Esin SAHIN PEKMEZ

Ege University, Izmir, TURKEY
E-mail: esin.pekmez@ege.edu.tr

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Contents

Abstract

The main purpose of this study was to find the effectiveness of using analogies to prevent misconceptions about chemical equilibrium. Nineteen analogies, which were based on dynamic aspects of chemical equilibrium and application of Le Chatelier's principle, were developed. The participations of this study consisted of 11th grade students (n: 151) from three high schools in Izmir, Turkey. The

Chemical Equilibrium Misconception Test (CEMT) was applied to the students both in the experimental and control group as pre- and post-tests. While the experimental group of students was instructed using mainly analogies, the traditional approach was used in the control groups. The result of the post-test showed that teaching with analogies was effective in preventing misconceptions. After the post-test, semi-structured interviews were conducted with 24 students from each school. The analysis of the interviews also showed that the experimental group students had fewer misconceptions than control group students.

Keywords: Analogy, chemistry Education, chemical Equilibrium, misconceptions

Introduction

Misconceptions are very important in the learning process and they have to be taken into account as these misconceptions can interfere with students' learning of scientific principles or concepts (Palmer, 2001; Taber, 2000). For this reason, the selection of teaching methods has an important factor in preventing students' misconceptions. Using analogies is one of the teaching methods. Analogies can help students build conceptual bridges between what is familiar and what is new (Glynn, 2007). They simplify visualization of the abstract concepts by the student.

Studies about analogies in science education have shown that analogies cause a significantly better acquisition of scientific concepts than the traditional instruction and help students integrate knowledge more effectively (Bilgin & Geban, 2001; Gadre, 1986; Piquette & Heikkinnen, 2005; Sarantopoulus &Tsaparlis, 2004; Stavy, 1991).

Using analogies is not new in chemistry education; they have been used through the ages by researchers to help students understand theoretical concepts (Huddle & White, 2000). For instance, Gadre (1986) used a seesaw analogy to teach the reading of manometers. At the end of the study, it was founded that using analogies effected learners' achievement positively. In his research, Silverstein (1999) used the big dog-puppy dog analogy. In this analogy, puppy dogs are restricted to a specific dog run; they represent bond electron pairs. Big dogs represent delocalized bond electron pairs. In another study, Silverstein (2000) used a football analogy to explain weak and strong acid-bases. He said that partial ionization is a difficult concept for some to comprehend; the phrase may not evoke much in the mind of a visual learner. Visual analogies are often helpful when abstract concepts are explained. Hence, in his analogy he likens an acid, which is a proton donor, to a quarterback. The quarterback is a football "donor," whose job is to deliver the ball by either passing it to a receiver or handing it off to a running back. Research was carried out by Chiu and Chen (2005) to determine the effects of dynamic computer analogy on 8th grade students' understanding of the behaviors of particles. The results of the study revealed that both static and dynamic computer analogies were significantly effective for learning the nature of particles.

Another chemistry topic with the most analogies is chemical equilibrium, since that topic includes the most abstract concepts such as its dynamic nature, the distinction between equilibrium and non-equilibrium situations, the mental manipulation of Le Chatelier's principle (Kousathana & Tsaparlis, 2002). Some of the analogies related to chemical equilibrium which were found in the literature are presented below:

Harrison and Buckly (2000) made a transparent simulation to explain dynamic equilibrium. They divided the students into two groups and gave them 24 small coins. Students in group A were given 24 coins, but students under B were not given any coins.

$$A\ (g) \underset{1/4}{\overset{1/2}{\rightleftharpoons}} B\ (g)$$

Students under A represented reactants, B represented products. While half of the reactants were converted to products, ¼ of products were converted back to reactants. This analogy illustrated very few aspects of chemical equilibrium such as reversibility of the reaction and the dynamic aspect. Key aspects of chemical equilibrium, like calculation of the equilibrium constant and application of Le Chatelier's principle, were not explained with this analogy. Similarly, Wilson (1998) developed three analogies to teach chemical equilibrium. Wilson used 40 matches to explain how a system reached equilibrium in the first analogy. In the second analogy, he explained the dynamic equilibrium starting with a different number of matches. In the third analogy, he used different reaction rates and temperatures to explain Keg.

According to literature review, it was determined that there were many analogies which explained the dynamic aspect of chemical equilibrium such as dancing couples, two groups throwing the balls/apples back and forth, fish between two aquariums and bees in a beehive (Dickerson & Geis, 1981; Olney, 1988; Russel, 1988; Sarantopoulos & Tsaparlis, 2004). In addition to these analogies, some analogies in the literature explained only the application of Le Chatelier's principle like a see-saw and rubber band and gas flow between syringes (Balkwill, 1976; Russel, 1988; Thomson, 1976). Among these analogies' most evident limitations are that (Raviolo & Garrtiz, 2009):

- They show an equality of "concentrations" of reactants and products in equilibrium (fish between two aquariums, bees in a beehive, gas flow between syringes).
- They do not explain equilibrium at molecular level (dancing couples, fish between two aquariums).

In this paper, we present chemical equilibrium analogies, including dynamic equilibrium, reversibility, equality of rates, calculation of equilibrium constant and the application of Le Chatelier's principle, based on assumption that analogies may help students learn abstract concepts by visualization (Treagust & Chittleborough, 2001).

It is very important that students' prior knowledge and misconceptions are determined and a teaching method (or combination of different methods) that overcomes misconceptions is selected. According to Çalik and Ayas (2005), in Turkey, most of the teachers do not know how to determine students' misconceptions in the learning process. On the other hand, from our teaching experiences in high schools and by informally talking with teachers, it was determined that many chemistry teachers prefer just lecturing with the chalk and talk method today. In this method, the teacher presents concepts to students who sit in the classroom, listen and write (Kara & Yesilyurt, 2007). Most of the time, teachers' focus on solving numerical problems rather than concept learning since students mainly need to solve numerical problems in the university entrance examination. Another reason why teachers prefer the chalk and talk method in chemistry lessons is that the high school chemistry curriculum consists of many topics, and teachers do not have enough time to design activities and materials (Nakipoglu, 2003). Therefore, this study can help chemistry teachers rethink their teaching methods and will inform them about using and importance of analogies in the teaching and learning process.

There are many studies that specifically investigate students' understanding of several chemical concepts such as a mole, atom, molecule, chemical equilibrium, chemical bonding and phase changing (Bar & Travis, 1991; Griffiths & Preston, 1992; Novick & Nussbaum, 1981; Özmen & Demircioglu, 2003; Wheeler & Kass, 1978). Among these topics, chemical equilibrium is one of the fundamental concepts in chemistry, like many other topics such as acid-base, electrochemistry, solubility, which are related to chemical equilibrium. Additionally, teaching chemical equilibrium takes up a large part of the chemistry curriculum in Turkey. As a result, the number of questions based on chemical equilibrium in university entrance examination is considerable. In this case, learning about chemical equilibrium correctly is vital to obtain high scores in the entrance examination. Results of the researches showed that subject of chemical equilibrium has been regarded as problematic for students (Banerjee & Power, 1991; Bergguist & Heikkinen, 1990; Gussarsky & Gorodetsky, 1990, Griffiths, 1994; Özmen, 2007). The most frequently encountered misconceptions according to the research are given below:

- No reaction occurs at equilibrium.
- The rate of the forward reaction is greater than the reverse reaction at equilibrium.
- Concentrations of the reactants are equal to the concentrations of the products at equilibrium.
- When one of the reactives is added, equilibrium always shifts to the products' side.
- When one of the reactives is added to the equilibrium mixture, only the concentration of products changes.
- If the amount of a reactant is increased, its concentration remains the same.
- When a solid substance is added to heterogeneous equilibrium systems, equilibrium is disturbed.
- The numerical value of Keq changes with the amounts of reactants or products.
- Concentration of the products or reactants change with the addition of a catalyzer.

Although these studies were conducted with subjects of different age levels, similar misconceptions were identified.

In this study, the aim was to investigate the effects of analogies related to chemical equilibrium in preventing students' misconceptions. Depending on this aim, these research questions were addressed:

- Is there any significant difference in the achievement mean scores between pre-tests of experimental and control groups?
- Is there any significant difference in the achievement mean scores between post-tests of experimental and control groups?
- Is there any significant difference in constructing knowledge between experimental and control groups?

Method

In this study, a pre-test/post-test with control group experimental design was used. The study was conducted in the spring semester of the 2007-2008 academic year. Before treatment, the pre-test was applied to determine students' prior knowledge about chemical equilibrium. The subject of chemical equilibrium was taught via using analogies in the experimental groups and at the same time control groups were taught via traditional method. After treatment; the post-test was administered to all subjects. Finally, semi-structed interviews were conducted with 24 students who were chosen according to their post-test scores. The instruction was accomplished in twelve course hours in all the classes. The experimental and control groups spent equal time for studying. However, the lessons in the experimental group focused on using the analogies that were designed to overcome students' misconceptions about chemical equilibrium.

Sample

This study was conducted with the participation of 151, 11th grade students in three high schools in Izmir, Turkey. A cluster sampling technique was used to select the sample. Both schools had two classes that were randomly assigned to experimental and control groups. It was considered appropriate to name the high schools with codes of letters (such as A, B, C) instead of using their names. Distribution of groups with respect to the schools is presented in Table I.

Table I. *Distribution of Groups with Respect to Schools*

High School	*Experimental Group*	*Control Group*
A	26	27
B	18	20
C	30	30

Instruments

In this study, although two measuring tools were used, the emphasis is on the data from semi- structed interviews.

• Chemical Equilibrium Misconceptions Test

• Semi- Structed Interviews

Chemical Equilibrium Misconceptions Test (CEMT)

Chemical equilibrium misconceptions test (CEMT) was developed in another research to diagnose students' misconceptions and the level of understanding of students about chemical equilibrium. In this research, CEMT was used as a tool to select the interview sample. Test items were developed according to the objectives and the concepts in the curriculum. In this process, some written sources were used to write the items such as secondary level science textbooks, related literature and instruments developed by other researchers (Bilgin, 2006; Kousathana & Tsaparlis, 2002; Piquette & Heikkinen, 2005; Quilez, 2004; Solomonidou & Stavridou, 2001;Thomas & Schwenz, 1998; Voska & Heikkinen, 2000). First, a two tailed test which included multiple-choice questions that require students to explain their reasoning behind each multiple choice answers was developed. Then the CEMT, composed of 30 items, was designed and the test was piloted by participation of 45 11th grade students for reliability. After the data collection, item analysis was done. According to results of item analysis, 5 items whose discrimination value ranges from 0,19 to 0,14 were removed from the test. Finally, reliability coefficient (KR-20) of the test was found to be 0.79. The test included all aspects of chemical equilibrium concepts and was administered to all subjects of the study as a pre-test and post-test.

Each question has one correct answer and four distractors. Each item requires students to select a definition of a scientifically complete response and reason for the correct answer. Four different categories that help to classify scientifically acceptable and unacceptable explanations were determined. These categories are below:

Scientifically Correct: Scientifically complete responses and correct explanations are a part of this category.

Partially Correct: Scientifically complete responses and incorrect explanations or scientifically incorrect response and correct explanations match this category.

Incorrect: This level involves completely unacceptable scienfitic responses or explanations.

No Response: Students who do not choose any response and make any explanations are put in this category.

An example of question of test item is presented in Table II.

Table II. *A Sample Question in CEMT*

The equilibrium between A gas and B gas is as follows:

$$\mathbf{aA}(g) \rightleftharpoons \mathbf{bB}(g)$$

When the volume of a container was increased at a constant temperature, reaction shifted to the reactants' side. According to this, what can we say about equilibrium?

A) a>b because when volume of the container was increased, equilibrium will proceed to make more moles of gases.

B) a>b because when volume of the container was increased, equilibrium will proceed to make fewer moles of gases.

C) b>a because when volume of the container was increased, equilibrium will proceed to make fewer moles of gases.

D) b>a because when volume of the container was increased, equilibrium will proceed to make more moles of gases.

E) It cannot be estimated because moles of gases don't have any influence on equilibrium shift.

Semi- Structed Interview

In order to determine whether there was any significant difference in constructing knowledge between experimental groups and control groups or not, interviews were carried out. The interview form consisted of five questions which were based on the reaction between carbon monoxide and chlorine forming carbonyl chloride.

$$CO_{(g)} + Cl_{2\,(g)} \rightleftharpoons CO\,Cl_{2(g)} + \text{heat}$$

Table III summarizes the content of interview questions. As it is seen in the Table III, the interview questions were about the explanation of chemical equilibrium and the application of Le Chatelier's principle.

Table III. *Content of Questions in the Interview*

Questions	Content
1st Question	Identification of chemical equilibrium
2nd Question	Changing equilibrium conditions (effects of concentration)
3rd Question	Changing equilibrium conditions (effects of temperature)
4th Question	Changing equilibrium conditions (effects of pressure)
5th Question	Identification of Le Chatelier’s principle

The interview questions were selected mostly from the published research papers (Banerjee, 1991; Costu & Ünal, 2004; Hackling & Garnett, 1985). The interview form was submitted to two experts for checking its reliability and validity, and additionally it was applied to a small group (5 students) for piloting. Interviews were conducted to examine students’ deeply held ideas about chemical equilibrium. 24 students from each high school (12 students from experimental group, 12 students from control group) were interviewed. A stratified sample technique was used to select the interview participants. First, students were categorized by the scores they received from the post-test (CEMT) as high achievers, middle (average) achievers and low achievers. Secondly, four students from each of these groups were randomly selected. The interview sessions were conducted individually with each student and lasted an average of 10-15 minutes. The responses that emerged from the participants were classified and coded to search for common themes in their responses. The researchers and a subject-matter expert coded the answers separately, and then the two results were compared. In this research, the percentage agreement was used to calculate reliability (percentage agreement = 0.90). The interview questions are presented in the findings section.

Procedure

As stated before, analogies are very important teaching tools that help students visualize abstract concepts (Heywood, 2002). In order to investigate the influences of analogies on preventing misconceptions about chemical equilibrium, nineteen analogies were developed in this research. The analogies are classified into two categories:

• Marble* models

• Molecular models.

The purpose of the using of marble models is to illustrate dynamic aspects of chemical equilibrium and applying of Le Chatelier's principle. After all, molecular models account for making and breaking of bonds at a molecular level. While ten analogies are related to marble models, nine analogies are related to molecular models. These analogies and their targets are presented in Table IV.

Table IV. *Analogies developed in this study and their targets*

Analogy	***Target***
1. Marble Model	Approach the equilibrium with reactants only
2. Marble Model	Approach the equilibrium with different amounts of reactants and products
3. Marble Model	The effects of increasing concentration of reactants on the equilibrium of the system
4. Marble Model	The effects of decreasing concentration of reactants on the equilibrium of the system
5. Marble Model	The effects of increasing concentration of products on the equilibrium of the system
6. Marble Model	The effects of decreasing concentration of products on the equilibrium of the system
7. Marble Model	Approach equilibrium as a heterogeneous system
8. Marble Model	The effects of adding a solid substance to a heterogeneous equilibrium system
9. Marble Model	The effects of increasing temperature on an endothermic equilibrium system
10. Marble Model	The effects of decreasing temperature on an endothermic equilibrium system
1. Molecular Model	Approach the equilibrium at a molecular level
2. Molecular Model	The effects of increasing the concentration of reactants on a chemical equilibrium system
3. Molecular Model	The effects of increasing concentration of products on a chemical equilibrium system
4. Molecular Model	The effects of decreasing concentration of reactants on a chemical

	equilibrium system
5. Molecular Model	The effects of decreasing concentration of products on a chemical equilibrium system
6. Molecular Model	The effects of increasing pressure on a chemical equilibrium system
7. Molecular Model	The effects of decreasing pressure on a chemical equilibrium system
8. Molecular Model	The effects of increasing temperature on an exothermic equilibrium system
9. Molecular Model	The effects of decreasing temperature on an exothermic equilibrium system

* A small colored glass ball, it isused to play a children's game.

The second marble analogy is presented below.

- Students were grouped into 4. The students were given 60 marbles in total.
- In each group, while one student represented reactants, the other one represented the products. The other two students recorded the data in their data table.
- At the beginning, reactants were given 50 marbles, and the products were given 10 marbles.
- For each cycle, student reactants randomly turned over some of the marbles, at the same time as the other student, representing the products, turned over a few of marbles.
- The number of marbles that the reactants and products had visible at the end of each cycle was recorded in a table (Table V) against time. Students also recorded the number of marbles turned over in each cycle and determined the change in the total number of marbles at reactants and products from the end of the one cycle to the next. Students were told that the number of marbles as reactants represented the concentration of reactants. At the same time, it was stated that the number of marbles that the products had represented the concentration of the products.
- This process was repeated until a stage was reached where the number of the reactants marbles turned over in a cycle that was equal to the number of marbles the products turned over. As it is seen in the Table VI, after the reaching equilibrium, equilibrium constant (K) is calculated.

Table V. *Marble Models Related to First Analogy*

Time (Min)	Number of Marbles of the Reactant	Number of Marbles of the Products	The Rate of Forward Reaction	The Rate of Reverse Reaction
0-10	50	10	20	7
10-20	37	23	18	8
20-30	27	33	15	10
30-40	22	38	14	12
40-50	20	40	12	12
50-60	**20 (Equilibrium)**	**40**	**12**	**12**
60-70	20	40	12	12
70-80	20	40	12	12
80-90	20	40	12	12

Table VI. *Equilibrium Constant*

	Number of Marbles of the Reactant	Number of Marbles of the Products	K (Equilibrium Constant)
Equilibrium	20	40	40/20 =2

The main purpose of this analogy was to explain how a system reaches equilibrium. The aspects of chemical equilibrium that this analogy illustrates are:

- The rates of reverse and forward reaction are equal at equilibrium.
- The rates of reverse reaction increase when equilibrium is reached.
- The rates of forward reaction decrease when equilibrium is reached.
- The dynamic aspect of chemical equilibrium.
- Reversibility of the reaction as the concept.
- Calculation of the equilibrium as a constant for the reaction.

Using this analogy, the researcher tried to prevent common students' misconceptions including:

- At equilibrium, no reaction occurs.

- When there is an equal mass or concentration of substances on both sides of equation, the reaction reaches equilibrium.
- T he rate of forward reaction is greater than the rate of reverse reaction at equilibrium.

The marble model could not explain the making and breaking of bonds at a molecular level. Therefore, molecular models which are based on formation of ammonia from H_2 and N_2 gases were developed.

$$\mathbf{N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)} + heat}$$

One of the molecular models is presented below.

- Students are divided into four, like in the first analogy.
- First, one student is given 10 blue balls which represent N_2, another student is given 20 grey balls which represent H_2. The student who represents NH_3 is not given any balls. The last student records the data in their data table (see Table VII).
- In the first stage 3 blue balls and 9 grey balls form 6 blue-grey balls which represent NH_3.
- In the second stage, 2 blue-grey balls are converted back to reactants as 1 blue ball and 3 grey balls. At the end of tenth minute, there are 8 blue balls (N_2), 14 grey balls (H_2) on the reactant side and 4 blue-grey balls (NH_3) on the product side.
- In the twentieth minute, while 2 blue balls and 6 grey balls produce blue-grey balls, 2 blue-grey balls decompose back to reactants as 1 blue ball and 3 grey balls. At the end of twenty minutes, there are 7 blue balls (N_2) and 11 grey balls (H_2) on the reactant side and 6 blue-grey balls (NH_3) on the product side.
- In the fortieth minute, students see that the total numbers of balls on both the reactant and the product sides are constant. So, chemical reaction reaches equilibrium. Finally, the equilibrium constant (K) is calculated (see Table VIII).

Table VII. *Marble Models Related to First Analogy*

Time (Min)	**Balls represent reactants**		**Blue-Grey Balls represent product (NH_3(g))**
	Blue Balls (N_2(g))	**Grey Balls (H_2(g))**	
0	10	20	----
0-10	8	14	4
10-20	7	11	6
20-30	**7 (Equilibrium)**	11	6
30-40	7	11	6
40-50	7	11	6
50-60	7	11	6
60-70	7	11	6
70-80	7	11	6
80-90	7	11	6

Table VIII. *Equilibrium Constant*

	Balls Represent Reactants		**Blue-Grey Balls Represent Product ($NH_{3(g)}$)**	**K (Equilibrium Constant)**
	Blue Balls ($N_{2(g)}$)	**Grey Balls ($H_{2(g)}$)**		
Equilibrium	7	11	6	(6)2 /7.(11)3 =0.004

Data Analysis

The analysis of the quantitative data was done by using the SPSS packet program. A one-way ANOVA test was used to determine whether there was a statistically significant difference between the experimental and control groups'pre-test and post-test scores. The significant level of .05 was considered in comparing groups. For quantitative data analysis all audio-tapes were transcribed and then the responses were coded. During this process, it was considered appropriate to identify the participants with codes of numbers and letters (such as SA1, SB2, SC3...) instead of using their names. For example, expression of SA1 represents the first student who studies at school A.

Findings

The results showed that there was no statistically significant difference between the groups with respect to their prior knowledge level ($p > .05$). These results indicated that students in both experimental and control groups were similar regarding the pretest (CEMT) scores (see Table IX).

Table IX. *ANOVA Results of Pre-Test*

	School	Groups	N	X	F	p
Pre-Test	A	Control	27	35.7037	.097	.756
		Experimental	26	35.0769		
	B	Control	20	28.8000	.002	.964
		Experimental	18	28.8889		
	C	Control	30	39.7333	.185	.669
		Experimental	30	40.4000		

The results of the post-test reflected that mean scores of experimental groups were higher than control groups and there were significant differences ($p <.05$). This result showed that teaching with analogies caused a significantly better acquisition of the concept than the traditional instruction (see Table X). The main difference between the two methods was that the analogies oriented instruction explicitly dealt with students' misconceptions relating chemical equilibrium while the traditional method did not.

Table X. *ANOVA Results of Post-Test*

	School	Groups	N	X	F	p
Post-Test	A	Control	27	47.8519	27.611	.000
		Experimental	26	57.2308		

	B	Control	20	42.6000	12.336	.001
		Experimental	18	50.4444		
	C	Control	30	51.2000	44.272	.000
		Experimental	30	65.0667		

Also, the t-test was used to determine if there was any significant difference between pre-test and post-test scores in the experimental and control groups. The level of significance was set at p= .05. When the results of the experimental groups' pre and post-test scores were analyzed using t-test, it was determined that there was a statistically significant difference between pre and post-test scores. For example, the experimental group in A high school went from a mean score of 35.07 to 57.23 (t =-12.458 and p= 0.00, p < .05), the experimental group in B high school went from a mean score of 28.88 to 50.44 (t = -13.038 and p = 0.00, p < .05) and the experimental group in C high school went from a mean score of 40.40 to 65.06 (t = -13.053 and p = 0.00, p < .05). Similarly, there was a significant improvement of the mean scores from the pre-test to post-test in the control groups. The control group in A high school went from a mean score of 35.70 to 47.85 (t = -9.055 and p= 0.00, p <.05), the control group in B high school went from a mean score of 28.80 to 42.60 (t= -9.564 and p = 0.00, p <.05) and the control group in C high school went from a mean score of 39.73 to 57.23(t = -9.899 and p= 0.00, p <.05).

Semi- Structed Interviews

Questions in the interview and analysis are presented below.

Question 1. Consider the following equilibrium system;

$$CO_{(g)} + Cl_{2\,(g)} \rightleftharpoons CO\,Cl_{2\,(g)} + \text{heat}$$

What do you understand from the statement that, "the system reaches equilibrium?" Table XI gives response categories and their frequencies and percentages relating to this question.

Table XI. *The Categories Belonging to First Interview Question*

Student's View	A High School				B High School				C High School			
	Experimental		Control		Experimental		Control		Experimental		Control	
	f	%	f	%	f	%	f	%	f	%	f	%
The rates of the forward and reverse reactions are equal when the system reaches equilibrium. *	7	58.3	3	25.0	4	33.3	1	8.3	5	41.7	2	16.7
Reaction continues even though it seems to have ceased.*	3	25.0	0	0.0	2	16.7	0	0.0	6	50.0	2	16.7
Display with two arrows.*	0	0.0	0	0.0	0	0.0	0	0.0	2	16.7	0	0.0
Existence of all the reactants and the products in the reaction.*	0	0.0	0	0.0	0	0.0	0	0.0	2	16.7	0	0.0
Concentration of the reactants must equal the concentration of the products at equilibrium	0	0.0	3	25.0	2	16.7	2	16.7	0	0.0	0	0.0
Mass of all species in the reaction mixture is equal at equilibrium.	0	0.0	0	0.0	0	0.0	0	0.0	1	8.3	3	25.0
Balancing chemical equation.	0	0.0	0	0.0	1	8.3	3	25.0	0	0.0	0	0.0
No changes in the chemical reaction.	0	0.0	0	0.0	1	8.3	1	8.3	0	0.0	0	0.0
Completion of the reaction.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2	16.7
Procedures about the molarity.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
Equivalence of the moles via molarity.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
Trying to change the reaction into its previous condition.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
Forward and reverse activation energies are equal at equilibrium.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
Stabilization of the temperature's heat.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0

* correct explanations

It is understood from Table XI that the number of students in the experimental groups who can explain the equilibrium correctly as "rate of the forward and reverse reaction are equal at equilibrium" or "reaction continues even though it seems to have ceased" is higher than the control groups. Morever, although experimental groups have some misconceptions such as "equilibrium is the equivalence of the concentration of reactive and products or the equivalence of the masses and balancing chemical equation", control groups have more misconceptions comparing to the experimental groups. This results showed that experimantal groups have better acquisition of chemical equilibrium concept than the control groups. Some of the explanations of students in the experimental groups are below:

"Features like pressure, colour and concentration do not change if the system reaches equilibrium. However, the act among molecules continues. There is a convertion from reactants to products and from products to reactants. The reaction seems to have ceased but the move goes on." SC6

"If the rates of the reverse and forward reaction are equal, then the reaction reaches equilibrium. It seems as if there is no change but reaction continues."SB7

"When the rate of forward reaction and reverse reaction are equal, system will reach equilibrium." SA1

When explanations of students in control groups are analysed, it is seen that most of the students explain concept of equilibrium correctly consisted of the most successful students according to their pos-test scores. Namely, while percentage of true explanations intensified among the students with higher conginitive development students, this percentage was very low among students with medium and lower cognitive development. According to the students' expressions, it was determined that the concept of equilibrium was associated with everyday terms such as equality and balance or perceptions as completion of the reaction because of macroscobic events stopped. The following views can be given as an example to these views:

"When the system reached equilibrium, the reaction completed. The amount of the reactants and the products is the same."SA13

"Concentration of the reactants and products are equal at equilibrium."SB9

"Equilibrium is balancing chemical equation and the number of atoms of each element is equal before and after reaction."SB14

"Reaction ends up when it approaches equilibrium. It becomes equal."SC15

The answers given to the question 2 "What kind of changes occurs in the system when Cl_2 gas is added to equilibrium mixture system ?" are given in Table XII.

Table XII. *The Categories Belonging The Second Interview Question*

Student's View	**A High School**				**B High School**				**C High School**			
	Experimental		Control		Experimental		Control		Experimental		Control	
	f	%	f	%	f	%	f	%	f	%	f	%
The system will shift to the side of consuming Cl_2. *	9	75.0	0	0.0	6	50.0	1	8.3	6	50.0	3	25.0
Equilibrium will shift to the products' side.*	5	41.7	2	16.7	7	58.3	1	8.3	8	66.7	3	25.0
Equilibrium is disturbed.*	3	25.0	1	8.3	3	25.0	1	8.3	5	41.7	1	8.3
Concentration of Cl_2 gas will be greater than its initial equilibrium value.*	3	25.0	2	16.7	3	25.0	0	0.0	6	50.0	3	25.0
While the concentration of $COCl_2$ gas has increased. the concentration of CO gas has decreased.	0	0.0	0	0.0	2	16.7	0	0.0	3	25.0	0	0.0
Nothing changes in the reaction.	0	0.0	0	0.0	2	16.7	4	33.3	0	0.0	3	25.0
Cl_2 is consumed.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
Concentration of Cl_2 remains the same.	0	0.0	2	16.7	0	0.0	1	8.3	0	0.0	0	0.0
Reaction decomposes as a substance was added.	0	0.0	1	8.3	0	0.0	1	8.3	0	0.0	0	0.0
Concentration of the substances remains the same.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
The amount of $COCl_2$ gas decreases.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
The amount of $COCl_2$ and CO gases do not change.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
Cl_2 gas is a catalyzer. so it is added.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0
Only the reverse reaction is occurring.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0

The purpose of this question was to find out the understanding of the students about the effects of concentration on equilibrium reactions. As can be seen in Table XII, correct explanations like "equilibrium is disturbed," "the system will shift to side of consuming Cl_2 gas" and "the equilibrium will shift to products' side" are a high percentage in the experimental groups. Students who made similar explanations are given below:

"Added gas disturbes the equilibrium. Reaction will shift to the products' side in order to reduce the effect. As Cl_2 gas is added, concentration of Cl_2 will increase. The reaction will proceed to remove some of the added Cl_2 gas. As a result of this, mole of $COCl_2$ gas increases but mole of CO gas decreases." SC1

"We can explain this situation according to Le Chatelier's principle. Reaction adjuts to re-establish equilibrium, so the equilibrium will shift to products to remove the added Cl_2 gas." SA8

"A reaction at equilibrium will proceed in a direction that relieves the stress put upon it. So equilibrium will shift to products." SB6

From the explanations of students in the control groups, it was determined that a few students made correct explanations such as the "reaction will shift to products' side," but they had misconceptions in the concentration of reactives and products with their initial equilibrium value. Some of the answers are stated below:

"Reaction shifts towards products and equilibrium is re-established. The amount of Cl_2 will be higher than its initial equilibrium value, but the amount of $COCl_2$ and CO will be the same." SA14

"Reaction reaches equilibrium again. Concentration of the substances stays the same." SA20

"Reactants collide to form products, but the amount of Cl_2 is the same with its initial equilibrium value. While the amount of CO reduces, the amount of $COCl_2$ goes up." SB19

Some of the explanations in the control groups are completely far from being scientific and they are all wrong. The expressions in that group are:

"Cl_2 is a catalyzer so it is added. It speeds up the reaction."SB17

"Reaction decomposes as a substance was added." SA21

The answers given to question 3, “What kind of changes happen in the system when we increase the temperature from 25 ºC to 50ºC?” are given in Table XIII.

Table X1II. *The Categories Belonging to The Third Interview Question*

Student’s View	A High School				B High School				C High School			
	Experimental		Control		Experimental		Control		Experimental		Control	
	f	%	f	%	f	%	f	%	f	%	f	%
The reaction will proceed to use up the added energy.*	6	50.0	0	0.0	5	41.7	1	8.3	7	58.3	2	16.7
The reaction will shift to reactants.*	10	83.3	2	16.7	6	50.0	1	8.3	10	83.3	2	16.7
While the concentration of CO and Cl_2 gases increase. the concentration of $COCl_2$ gas decreases.*	3	25.0	0	0.0	2	16.7	0	0.0	0	0.0	0	0.0
Equilibrium is disturbed.*	4	33.3	2	16.7	4	33.3	1	8.3	4	33.3	1	8.3
The rate of the reaction increases.	2	16.7	3	25.0	3	25.0	2	16.7	3	25.0	3	25.0
Equilibrium constant (Keq) changes.	0	0.0	0	0.0	0	0.0	0	0.0	3	25.0	1	8.3
The rate of the forward reaction decreases.	0	0.0	1	8.3	0	0.0	1	8.3	0	0.0	0	0.0
The rate of the reverse reaction doesn’t change.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	8.3
Reaction ends up faster.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	8.3
No change happens in the reaction.	0	0.0	0	0.0	1	8.3	2	16.7	0	0.0	0	0.0
Forward activation energy decreases.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0
Activation energy increases.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0
Boiling increases.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0
Concentrations of all species in the reaction mixture increase.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
Gases expand and diffuse.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0
Durability of products is ensured.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0

The correct answer for this question is that the "reaction will shift to reactants' side, concentration of reactants increase and concentration of products decrease." It is understood from Table XIII, there are more students who made correct explanations in the experimental groups than in the control groups. Some of the students who explained similar ideas are stated below:

"As the reaction is exothermic, reaction will shift to use up the added energy, namely the direction of reactants. While the concentration of $COCl_2$ *is decreasing, concentrations of CO and* Cl_2 *increase." SA1*

"A reaction at equilibrium will proceed in a direction that relieves the stress put upon it. If temperature is increased, the reaction will proceed to use up the added energy. Because energy is a product. Consequently, reaction shifts towards reactants." SA5

"Temperature is increased. In such a situation, reaction shifts to the reactants' side and equilibrium is re-established." SC3

"If a system is at equilibrium and temperature is changing, the system adjusts to re-establish equilibrium in such a way as to partially counteract the imposed effect. Reaction will shift to reactants' side." SB2

It is seen from expressions of students in the control groups that students can explain the relationship between temperature and the rate of the reaction rather than temperature and equilibrium. Also, it was detected from the answers that students have some misconceptions coming from the previous unit of chemical equilibrium. The especially striking answers are below:

"If temperature is increased, that means the energy is increasing. Activation energy goes up." SB15

"When temperature is increased, reaction will shift to the reactants' side. Because the rate of the reverse reaction will increase, but the rate of the forward reaction will decrease." SA13

"As reaction is exothermic, while the reverse reaction speeds up, forward reaction slows down." SB20

Some of the misconceptions are originally found with this research. These explanations are given below: "Boiling temperature increases. More gas comes up into the air." SC18

"Temperature is increased. Molarities of all species in the reaction increase because molarity and heat are directly proportionl."SA21

"Reaction ends up faster because the temperature is increased."SC19

The answers given to the question 4, "What kinds of changes happen in the system when the volume of the container is halved? are presented in Table XIV.

***Table XIV.** The Categories Belonging The Fourth Interview Question*

Student's View	**A High School**				**B High School**				**C High School**			
	Experimental		Control		Experimental		Control		Experimental		Control	
	f	%	f	%	f	%	f	%	f	%	f	%
Equilibrium is disturbed.*	4	33.3	2	16.7	0	0.0	0	0.0	4	33.3	1	8.3
Reaction will shift to partially restore the original pressure.*	4	33.3	1	8.3	5	41.7	0	0.0	7	58.3	2	16.7
Reaction will proceed to make fewer moles of gas.*	6	50.0	1	8.3	3	25.0	1	8.3	9	75.0	2	16.7
Reaction will shift to products.*	6	50.0	1	8.3	3	25.0	0	0.0	5	41.7	1	8.3
Pressure increases.	7	58.3	4	33.3	5	41.7	2	16.7	9	75.0	4	33.3
While the mole of CO and Cl_2 gases decreases. the mole of $COCl_2$ gas increases.	2	16.7	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Equilibrium will proceed to make more moles of gas.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	8.3
Air pressure becomes equal with the pressure of the chemical substances.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0
If there is a catalyzer in reaction. The rate of reaction is increased. Otherwise it will be initially unchanged.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	8.3
When the volume decreases, mole of gases decreases too.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	8.3
No change occurs in the reaction.	0	0.0	3	25.0	1	8.3	3	25.0	0	0.0	1	8.3
Reaction decays.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0

As can be seen in Table XIV, both students in the experimental groups and the control groups can construct a bridge between the concepts of volume and pressure.

On the other hand, a few students in the control groups made correct explanations about the effects of volume on equilibrium reactions. Some of explanations in the experimental groups are stated below:

"This is a prediction made by Le Chatelier's principle. When volume is decreased, pressure is increased. Reaction will shift as to partially restore the original pressure. Namely, it will proceed towards the side with fewer moles of gas. As time goes on, while CO and Cl_2 reactants are produced, $COCl_2$ is consumed. As a result of this, moles of reactants are decreased, mole of product is increased." SA4

"We look at the mole of the reactants and products. There are two moles of gas particles on the left hand side of the reaction and one mole of gas particle on the right hand side of the reaction. Decreasing the volume increases the pressure. Reaction will shift to fewer moles of gas to reduce the pressure. It will shift to the products' side." SB3

"Maximum entropy and minimum energy are important for reaction. The two tendencies oppose each other at equilibrium. If a system has reached equilibrium it will remain at equilibrium. When equilibrium is disturbed, the equilibrium position will shift in the direction which tends to minimize the effect of the disturbance. Reducing the volume of this equilibrium system is equivalent to increasing the pressure. Equilibrium will shift to fewer moles of gas." SC5

It is understood from these expressions that students in the experimental groups can explain the effects of volume on the equilibrium reactions correctly.

It can be seen that many students in the control groups explain relationship between pressure and volume instead of the effects of volume on equilibrium reactions. Besides scientifically correct explanations, the incorrect ones are also striking. Some of the students' answers are as follows:

"Nothing changes as there is a reaction between these chemicals. These substances are the components that are not affected by volume change." SA18

"As, the number of atoms of each element is equal before and after reaction, volume change won't affect this." SC22

"There is the equivalence of air pressure with chemical pressure." SB13

"Gases are compressible, pressure is increased, reaction decays." SB10

The answers given to the question 5, "What is Le Chatelier's principle?" are presented in Table XV.

Table XV. *The Categories Belonging to the Fifth Interview Question*

Student's View	**A High School**				**B High School**				**C High School**			
	Experimental		Control		Experimental		Control		Experimental		Control	
	f	%	f	%	f	%	f	%	f	%	f	%
When a system at equilibrium is disturbed. the system will shift its equilibrium position in the opposite direction*	8	66.7	0	0.0	3	25.0	0	0.0	5	41.7	0	0.0
Equilibrium tends to compensate for the effects of disturbance.*	3	25.0	1	8.3	3	25.0	0	0.0	5	41.7	0	0.0
It expresses how the system will reach equilibrium again when the equilibrium is disturbed*	3	25.0	1	8.3	2	16.7	0	0.0	4	33.3	2	16.7
When reagents are added or the temperature or pressure is changed at equilibrium. equilibrium position will shift to which direction.*	0	0.0	0	0.0	3	25.0	0	0.0	0	0.0	0	0.0
It gives information about the reaction.	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	25.0
It is a chemical event.	0	0.0	0	0.0	0	0.0	2	16.7	0	0.0	0	0.0
It explains the relationship of pressure-volume-mole in gases.	0	0.0	0	0.0	0	0.0	2	16.7	0	0.0	1	8.3
It is the principle that explains the relationship between the reaction and equilibrium constant (Keq).	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0
It is the balancing chemical equation.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0
It is a principle related to the electrons surrounding the atoms.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0
It is the principle that determines the mole.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0
It explains that the mass of the products by a chemical reaction is always equal to the mass of the reactants.	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0	0	0.0
It is a principle about the equilibrium mixture.	0	0.0	0	0.0	0	0.0	0	0.0	1	8.3	0	0.0
It is a gas law.	0	0.0	1	8.3	0	0.0	0	0.0	0	0.0	0	0.0

In this question, the students were supposed to describe Le Chatelier's principle in their own words. The students are expected to answer that question, "if a stress is applied to a system at equilibrium, the system will adjust so as to partially relieve the stress." The word stress here means any disturbances to equilibrium, such as temperature, pressure or concentration. When Table XV is analyzed, it seen that most of the students in the experimental groups explain Le Chatelier's principle correctly. Some of the answers that the students in the experimental groups are given below:

"If a system has reached equilibrium it will remain at equilibrium. Since maximum entropy and minimum energy are compatible with each other at equilibrium. Equilibrium system tends to compensate for the effects of disturbance. For example, if one of the reactants is added to equilibrium mixture, equilibrium will shift to products' side to use up the added reactant." SC5

"When equilibrium is disturbed, the equilibrium position will shift in the direction which tends to counteract the effect of the disturbance. For example, if a substance is added, the equilibrium position shifts to use up the added substance." SA4

"It explains that whether the reaction will shift to the products or reactants. When a system at equilibrium is disturbed, the system will shift its equilibrium position in the opposite direction. It states that when reagents are added or the temperature or pressure is changed at equilibrium, equilibrium position will shift to which direction." SB7

It is especially seen from these explanations in the control groups that the students confuse Le Chatelier's principle with the other principles and laws in chemistry such as the conservation of mass, Gay Lussac's law, Charles's law and Boyle Mariotte's law. Some of the expressions are below:

"We balance chemical equations according to this principle. The same number of atoms of each element appearing in reactants must appear in the products." SB13

"It is one of the principles in chemistry. It explains that the mass of the products by a chemical reaction is always equal to the mass of the reactant." SB15

"It is the principle that determines the mole of the atom." SB18

"It is a principle showing the relationship between pressure, mole, volume and the temperature of the gases." SC22

Some of the explanations are completely far from being scientific and they are all wrong. The expressions in that group are as follows:

"It is a principle related to the electrons surrounding an atom." SB21

"It determines the reactions between molecules." SC23

"It is a principle about equilibrium mixture." SB22

Conclusion and Discussion

Nowadays, many researchers accept that students' misconceptions should be taken into account during the curriculum development and when creating teaching materials. Students' meaningful understanding of scientific concepts and topics has an important role for science education programs in order to attain their goals (Kiliç & Saglam, 2009). For this reason, in this study, it was aimed to investigate the effectiveness of analogies on preventing students' misconceptions. The use of analogies to teach chemical equilibrium has been discussed for many years. In the literature review, there was found to be different analogies for the explanation of chemical equilibrium, but these analogies represented specific aspects of chemical equilibrium, such as dynamic aspect and the application of Le Chatelier's principle. In other words, a few analogies demonstrate both other aspects of chemical equilibrium like equality of rates, reversibility, calculation of the equilibrium, constant equilibrium and its dynamic aspect and the appliation of Le Chatelier's principle.

Analogies developed in this research aim to make new, abstract concepts such as dynamic aspects of chemical equilibrium, applying Le Chatelier's principle, reversibility, equality of rates and calculation of the equilibrium constant more concrete and support the learning process.

The findings of the study proved that although there were no significant differences between experimental and control groups in each high school before the instruction ($p>.05$), significant differences were found between groups after the instruction ($p<.05$). According to the results of the post-test, mean scores of experimental groups were higher than the control groups. Both this data and individual interview results showed that teaching with analogies have a positive effect on students' understanding and also prevented fundamental misconceptions. Though analysis of interviews indicated that both experimental groups and control groups have misconceptions in the areas related to approach to equilibrium and changing equilibrium conditions, these misconceptions condensed in the control groups. In the teaching of these concepts, in addition to analogies that we used in this study, using different technologies or methods, such as computer-based activities and laboratory activities, could be suggested. Also, it was determined that the percentage of correct explanations in the experimental groups was higher than control groups according to interview results. This study is evidence that teaching with analogies is an effective teaching method for higher learning achievement and in preventing misconceptions. In this respect, we thought that the present study would be an important source for the chemistry teachers in Turkey as well as that in other countries.

From some explanations to first interview questions, we have concluded that the students' misconceptions about chemical equilibrium generally originated from their experiences in everyday life (such as SA13, SB9). Accordingly, when preparing teaching programs and materials, it is very important that students' prior knowledge is determined.

In this study, it was observed that a semi-structured interview consisting of five questions is very effective in determining misconceptions and developing a deeper understanding of the students. Some misconceptions that were determined through the interview, such as at equilibrium, concentrations of reactants and products are equal, no changes occur; adding of reactants to an equilibrium reaction does not effect the concentration of substances; and increasing of temperature does not influence the rate of reverse reaction, are similar to the literature (Banerjee & Power, 1991, Griffiths, 1994; Özmen, 2007; Sözbilir, Pinarbasi & Canpolat, 2010). Existence of these similar misconceptions shows that many learners do not understand chemical equilibrium correctly; however, these learners were studied in different counties. Also, it was found that some chemistry teachers had some misconceptions about chemical equilibrium, much like their own students (Cheung, 2009; Cheung, Ma & Yang, 2009).

In this case, curriculum developers and teachers should take some responsibility to make teaching more effective and to overcome misconceptions. For example, high school chemistry curriculum should focus more on samples related to real life situations and examples. In that way, many chemistry topics like chemical equilibrium should be easier to learn. In addition, some practical activities related to chemical equilibrium could take place in the curriculum. Thus, high school chemistry curriculum in Turkey was modified in 2008-2009 academic year. New chemistry curriculum based on the principles of the constructivist approach. This was a radical shift from a teacher-subject based approach to student-based approach. Firstly, new chemistry curriculum was implemented in the ninth grades of high schools in the 2008-2009 academic year. Eleventh graders' chemistry curriculum, which includes the subject of chemical equilibrium, will start to be implemented in 2010-2011 academic year. So, we do not yet have enough information to evaluate this new chemistry curriculum. However, according to our informal talk with chemistry teachers, it emerged that they were not adequately informed about the program and could not understand the program based on constructivism. For an education program to be successful, it is very important that teachers who are leading the program have the knowledge and skills required (Kirikkaya, 2009). For this reason, teachers should be given in-service courses concerning contemporary methods, technique, measurement and evaluation, required by the program. Particularly, a focus should be on how activities develop and apply the in-service courses, as most teachers do not have enough competence regarding these types of activities.

Another responsibility that teachers should be aware of is students' prior knowledge and misconceptions, because they are strong predictors of student achievement in chemistry. Because of this, teachers should control students' prior knowledge before teaching of subject matter (Özmen, 2007). In this process, teachers should be able to use diagnostic tests or word association test for determining students' prior knowledge. Then teachers should select a suitable teaching method according to students' prior knowledge.

Researchers have shown that the teacher centered traditional approach fails to prevent misconceptions (Acar &Tarhan 2007, Bodner 1986; Felder 1996). So, it is very important to develop alternative methods that can correct or prevent students' misconceptions. One of the alternative methods is using analogies. Teaching with analogies allows students to actively participate in the learning process. Analogies can help students relate new information to prior knowledge, to integrate information for one subject area into another, and to relate classroom information to everyday experiences. In this process, students observe, record data and conclude that these skills are important in terms of converting abstract knowledge into concrete knowledge, learning and overcoming misconceptions (Yildirim et al., 2010). Previous researchers have also emphasized that analogies support meaningful learning and help students to construct topics easily; these are referred to as hard issues and include abstract concepts like chemical equilibrium (Harrison & Jong, 2005; Ganaras, Dumon & Larcher, 2008, Kargiban & Siraj; 2009). In addition, analogies are funny for many students (Sarantopoulos & Tsaparlis, 2004). Therefore, using analogies to teach chemistry may positively influence students' motivation to study chemistry. In conclusion, similar studies should be continued, and analogy activities should be developed for chemistry lessons as well as the other science fields.

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