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HOW CAN SECONDARY SCHOOL STUDENTS PERCEIVE CHEMICAL EQUILIBRIUM?

ABSTRACT

This study was conducted to determine secondary school students' conceptual difficulties in understanding of chemical equilibrium. The sample of study involved one hundred fifty-one 11th grade students from three different secondary schools in Izmir. For the data collection, chemical equilibrium misconception test (CEMT) and semi-structured interview were used. In the analysis of data, students' responses in CEMT were categorized and also the data obtained from interviews were coded. At the end of study, it was revealed that students had some misconceptions about chemical equilibrium. Some of these misconceptions are parallel to the literature and some of them are originally found with this research. Some of the misconceptions, which we have not come across while reviewing literature are: When a solid substance is added to an equilibrium system at constant temperature, K_{eq} increases, or decreases. When all reactants are consumed, the chemical reaction reaches equilibrium.
Keywords: Chemical Equilibrium, Chemistry Teaching, Concept, Misconception, Le Chatelier's Principle

ORTAÖĞRETİM ÖĞRENCİLERİ KİMYASAL DENGE KONUSUNU NASIL ALGILAMAKTADIRLAR?

ÖZET

Bu çalışma, ortaöğretim öğrencilerinin kimyasal denge konusundaki kavramsal problemlerini saptamak amacıyla yürütülmüştür. Çalışmanın örneklem grubu, İzmir'deki üç farklı liseden 11. sınıflardan yüz elli bir öğrenciyi içermektedir. Çalışmada, veri toplama amacıyla kimyasal denge kavram yanılgısı testi(KDKYT) ve yarı yapılandırılmış görüşme kullanılmıştır. Verilerin analizi için, öğrencilerin KDKYT'de verdikleri cevaplar kategorilere ayrılmış, görüşmeden elde edilen veriler ise kodlanmıştır. Çalışma sonucunda, öğrencilerin bu konu ile ilgili bazı kavram yanılgılarına sahip oldukları saptanmıştır. Saptanan bu kavram yanılgılarından bazıları literatürle paralellik gösterirken, bazıları ilk olarak bu araştırmada saptanmıştır. Literatürde rastlanmayan kavram yanılgılarından bazıları şunlardır: Dengedeki bir sisteme, katı madde eklendiğinde (K_d) artar ya da azalır. Bir tepkimedeki tüm reaktifler tükendiğinde, sistem dengeye ulaşır.
Anahtar Kelimeler: Kimyasal Denge, Kimya Öğretimi, Kavram Yanılgısı, Kavram, Le Chatelier Prensibi

1. INTRODUCTION (GİRİŞ)

It is very important that students learn basic science concepts correctly because these concepts are fundamental for learning the other notions that are related to higher-level science concepts. Because of this reason, many studies have been carried out to find out and overcome students' misconceptions in chemistry.

If a person have some conceptions which are not accepted scientifically, this is defined this person have misconceptions about this subject. The studies have shown that students have prior knowledge [1]. Driver's studies have shown that student have their knowledge about varieties of concepts and most of the time, their prior knowledge consist of several misconceptions. These concepts are valuable for students as they construct by themselves as a result of their experience. That is the reason, students resist to change their misconceptions [2].It is pointed out that the main reason of the failure of students in chemistry lesson is that students cannot learn the concepts of chemistry accordingly; they cannot get the higher-level concepts that they are supposed to learn [3]. The misconceptions that students have must be determined in the phase of preventing the misconceptions. To prevent students have misconceptions, firstly, teachers must learn students' existing knowledge before teaching. Some of the methods such as concept maps, prediction-observation-explanation, interview about the events and the instances, interview about the concepts, drawings, word association and diagnostic tests can be used to determine of students' misconceptions [4 and 5].

Since most of the chemistry concepts are abstract, this causes the students construct the concepts in their minds in a different way. In other reason, their daily life terminology and scientific terminology are different. For example, in a daily life for most of the people equilibrium is the same with equality of weighing machine. Many studies have been conducted on how much the students understand the basic chemistry concepts and what the misconceptions related to these concepts are. It has been confirmed that the students' misconceptions mostly intensify on the abstract concepts such as mole concept, atom, molecule, chemical equilibrium, chemical bonding, electro-chemistry and phase changes [6, 7, 8, 9 and 10]. Students' misconceptions are mostly about chemical equilibrium among these subjects. As stated, the main reason is that the concept is abstract and the terminology used in daily life is used differently in this field [11, 12 and 13].In a research, Griffiths [14] aimed to find out students' misconceptions in chemistry. This research showed that students have mostly misconceptions about chemical equilibrium that are stated below:

- The rate of the forward reaction is greater than the reverse one at equilibrium.
- No reaction occurs at equilibrium.
- A catalyst affects the rates of the forward and reverse reactions differently.
- Concentration of the products or reactants changes with addition of a catalyzer.

Hackling and Garnett's [15] findings are consistent with the findings of Griffiths. It was found out that students could solve numerical problems but fail to answer conceptual questions. In addition, Hackling and Garnett determined that most of the misconceptions intensify conceptual subjects such as the dynamic equilibrium, forward and reverse reactions, the effect of catalyzer.

Similar findings have been reported by Quilez and Solaz [16]. Quilez and Solaz aimed to identify chemistry conceptions students' use when solving chemical equilibrium problems in this research. Common students' misconceptions of chemical equilibrium determined in research were:

- When one of the reactive is added, equilibrium always shifts to products' side.
- When a solid substance is added to heterogeneous equilibrium systems, equilibrium is disturbed.
- If an inert gas is added to equilibrium mixture, equilibrium is never disturbed. Since inert gases do not react.

Wheeler and Kass [17] to determine misconceptions about chemical equilibrium conducted another research. They found that students had difficulty in understanding the following areas of chemical equilibrium: mass and concentration, reaction rate and degree, constancy of chemical equilibrium, and Le Chatelier's principle

Similarly, Gussarsky and Gorodetsky [18] probed students' understanding of chemical equilibrium. They found that chemical equilibrium was perceived as circus acrobatics, bicycle riding, weight scales and besides, most of the students did not understand the dynamic structure of the chemical equilibrium.

In another study that had been done by Atasoy, Akkuş and Kadayıfçı [19], several misconceptions about chemical equilibrium had been determined in 10^{th} grade students. For example, some students believed that the bigger the mol number of the products, the bigger the equilibrium constant. Another research was conducted by Quilez [20]. In this research, Quilez aimed to determine learners' understanding of changes in concentration in gaseous equilibrium systems. For this aim, he administered to two questions both high school and fourth-year university students and to both pre-service and in-service high school chemistry teachers in Spain. At the end of study, it was revealed that equilibrium law was not used at all by students; a minor number of teachers mentioned the equilibrium constant in their explanations.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

Although, there were many researches about identification of misconceptions about chemical equilibrium in the literature, mostly, quantitative or qualitative methods were used in these researches, only a few studies included both quantitative and qualitative methods [19 and 21]. At the same time, these studies focused on only one side of chemical equilibrium such as dynamic aspect or applying of Le Chatelier's principle. Therefore, this study was developed to investigate students' misconceptions about chemical equilibrium as quantitative and qualitative.

The main aim of this study is to investigate 11^{th} grade students' conceptual difficulties in understanding chemical equilibrium after they had received instruction on chemical equilibrium. So, the following questions were tried to be answered in this study:

- Which of the common misconceptions about chemical equilibrium reported by other researchers are held by our 11^{th} grade students?
- Do they hold new misconceptions about chemical equilibrium?

3. METHOD (YÖNTEM)

Quantitative and qualitative methods were used in order to carry out this research. For this purpose; firstly, chemical equilibrium misconceptions test was applied to 151 randomly selected grade 11 students from 3 secondary schools in Izmir. Secondly, semi-structured interviews were carried out with 72 students from the same schools.

Both of the methods, the applying test and the semi-structured interview, were conducted by the same researchers.

3.1. Sample (Örneklem)

The sample of this study consisted of 151, 11th grade students who were studying at three different high schools in 2007-2008 academic years in Izmir, Turkey. The study was conducted one week later when they had received instruction on chemical equilibrium. The teaching period continued twelve course hours, each 40 minutes, all completed in four weeks.

3.2. Instruments (Araçlar)

Two instruments were used in this study in order to collect data. One of them was chemical equilibrium misconceptions Test (CEMT). The other one was semi-structured interview.

3.2.1. Chemical Equilibrium Misconceptions Test (CEMT) (Kimyasal Denge Kavram Yanılgısı Testi)

Chemical equilibrium misconceptions test was developed by the researchers to investigate students' understanding of chemical equilibrium. This test included 25 multiple-choice questions. Each question has only one correct answer and four distracters. Each question requires students to select definition of scientifically complete response and reason of this.

This test involved questions about chemical equilibrium such as: (a) approach of the system to equilibrium; (b) the equilibrium situation; (c) the changes in the equilibrium conditions (temperature, concentration, pressure, volume) (d) inert gas addition. For content validity, the text was examined by a group of experts in chemistry and education, and by the course instructors for the appropriateness of the questions to the instructional objectives. The reliability of the test was found to be 0.79 using item analyses.

3.2.2. Interview (Görüşme)

In order to get deeper knowledge about students' conceptions about the chemical equilibrium, semi-structured interviews were carried out with 72 students, who completed CEMT. 24 students from each schools participated in the interview. Interviewees were selected considering students' performance in the CEMT. The interview form consisted of five questions. Content of questions in the interview are presented in Table 1. In the interview, questions were based on the reaction between carbon monoxide and chlorine forming carbonyl chloride.

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

Tablo 1. Content of questions in the interview
(Tablo 1. Görüşme sorularının içeriği)

Questions	Content
1st Question	Identification of chemical equilibrium
2nd Question	Changing equilibrium conditions (effects of concentrations)
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 mostly selected from the published research papers [15, 19, 20 and 21]. The interview form was submitted to two experts for examination and rearranged in line with their opinions. The developed interview form was applied to a small group (5 students) as a pilot study. The interview form was prepared after all these corrections. The interview sessions were conducted separately with each student and lasted an average of 10-15 minutes. The interviews were analyzed and coded to search for common themes that emerged from participant responses. In this study, coding was made by the researchers and a subject-matter expert separately and then compared. Reliability of content analysis is closely related to category arrangement. In this research, percentage agreement used to calculate reliability (percentage agreement = 0. 90).

3.3. Analysis (Veri Analizi)

In analyzing test items, first, students' responses were analyzed according to the following categories used by Abraham et al[22]. These categories are below:

- **Scientifically Correct (SC):** Scientifically complete response and correct explanations take part in this category.
- **Partially Correct (PC):** Scientifically complete response and incorrect explanations or scientifically incorrect response and correct explanations match this category.
- **Specific Misconceptions(SM):** This level involves completely scientifically unacceptable response or explanations.
- **No Response (NR):** Students who does not choose any response and make any explanations are put in this category.

Secondly, frequency and proportion of students' responses were calculated and presented in Tables. The misconceptions that were identified in the CEMT are summarized in Table 11 and Table 12.

Data from interviews were analyzed by making content analyzed. In the process of data analysis, these steps were followed:

- Transcribing data.
- Coding the data.
- Constructing categories.
- Reliability analysis.
- Identification of repeated categories and showing them as frequency and percentage.
- Writing results and interpretations.

All audio-tapes were transcribed by the authors. Subsequent analysis identified codes within the responses. This led to construction of categories. During this process, it was considered appropriate to name the participants with codes of numbers and letters (such as SA1, SB2, SC3...) instead of using their names because they were guaranteed that their names would not reveal during the research. For this reason, the statements were presented with these codes in findings section of the study. For example, expression of SA1 represents the first student who studies at A high school

4. FINDINGS AND DISCUSSION (BULGULAR VE TARTIŞMA)

The results from the analysis of CEMT and interview indicated that students had misconception about chemical equilibrium under five headings. These are below:

- Identifying the chemical equilibrium.
- Changing equilibrium conditions (removal or additional of substances at the equilibrium).
- Changing equilibrium conditions (increasing or decreasing temperature at the equilibrium)
- Changing equilibrium conditions (changes of volume and pressure at equilibrium).
- Identifying Le Chatelier's principle.

These headings are presented below.

Identifying the chemical equilibrium

In the interview, first question was designed to reveal students' understanding of chemical equilibrium. This question is below:

Question 1. Consider the following equilibrium system;

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

"What do you understand from statement of "the system reaches equilibrium?" Table 2 shows response categories and their frequencies and percentages related to this question.

Table 2. The categories belonging to first interview question
(Tablo 2. Birinci görüşme sorusuna ait kategoriler)

Student's View	Frequency (f)	Percentage (%)
The rates of the forward and reverse reactions are equal when the system reaches equilibrium *	22	30,5
Reaction continues even though it seems to have ceased*	11	15,3
Display with two arrows	2	2,8
Existence of all the reactants and the products in the reaction	2	2,8
Concentration of the reactants must equal the concentration of the products at equilibrium	15	20,8
Mass of all species in the reaction mixture are equal at equilibrium	4	5,5
Balancing chemical equation	4	5,5
No change in the chemical reaction	2	2,8
Completion of the reaction	2	2,8

As it is seen in Table 2, 30,5% of the students explain that rate of the forward and reverse reaction are equal at equilibrium and 15.3% of them make a true statement as reaction continues even though it seems to have ceased. The following view can be given as an example to these views:

"It is said that if the rate 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

However, it is understood from the answers that the students have unscientific concepts about the chemical equilibrium. 20.8% of the students perceive the equilibrium as the equivalence of the concentration of reactive and products; and 5.5% of them perceive as the equivalence of the masses.

SA15 of the students' expression:

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

And SB22 of students' declare:

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

The expressions above reveal that these students regard the equilibrium physically and they do not understand the chemical equilibrium. This situation is also common language problem.

Another misconceptions determined on the students in 5.5% ratio is that the equilibrium was perceived as the balancing chemical equation. When we look at the expressions of the student, as in the example below, the student see the balancing chemical equation as if it is same with the equilibrium.

"Equilibrium is balancing chemical equation and the number of atoms of each element is equal before and after reaction" SA16.

In addition, four questions in the CEMT (Questions 5, 6, 12 and 14) were designed to determine students' understanding about chemical equilibrium. One of them (Question 6) and students' responses to it are presented in Table 3.

Table 3. Question 6 in the CEMT and students' responses
(Tablo 3. KDKYT yer alan 6. soru ve öğrencilerin cevapları)

Consider the following reversible reaction that is in a state of equilibrium

$$2NH_{3(g)} \rightleftarrows N_{2\,(g)} + 3H_{2(g)}$$

What can we say about the equilibrium concentrations of NH_3 gas?

A) Concentration of NH_3 is constant because forward reaction stops at equilibrium.
B) Concentration of NH_3 is constant because reverse reaction stops at equilibrium.
C) *Concentration of NH_3 is constant because the rates of forward and reverse reaction are equal at equilibrium.
D) Concentration of NH_3 increases because only reverse reaction occurs at equilibrium.
E) Concentration of NH_3 decreases because only forward reaction occurs

	Category	f	%
Question 6	**SC**	31	20,5
	PC	30	19,9
	SM(d)	15	9,9
	SM(e)	10	6,6
	NR	65	43,0

(*) indicates a correct response

In this question, it was purposed to reveal how concentration of reactant, the rate of forward and reverse reaction change at equilibrium. As it seen clearly from Table 3, although most of the students' responses grouped under SC (20.5%) and NR (43.0%)

categories, a significant percentage of students held misconceptions. While 9.9% of the students believed that concentration of NH_3 increases because only reverse reaction occurs at equilibrium, 6.6% of the students believed that concentration of NH_3 decreases because only forward reaction occurs at equilibrium.

- **Changing equilibrium conditions (removal or additional of substances at the equilibrium):** One of the questions related to application of the Le Chatelier's principle in the interview is second interview questions. In this question, effect of concentration change on equilibrium system was aimed to determine. This questions and answers to it are presented below:

Question 2. "What kind of changes occurs in the system when Cl_2 gas is added to equilibrium mixture system?"

Table 4. The categories belonging to second interview question
(Tablo 4. İkinci görüşme sorusuna ait kategoriler)

Student' View	Frequency (f)	Percentage (%)
The system will shift to side of t consuming Cl_2 *	25	34,7
Equilibrium is disturbed.*	14	19,4
The system will shift so as to remove some of the added material*	9	12,5
Equilibrium will shift to products' side*.	26	36,1
Concentration of Cl_2 gas will be greater than its initial equilibrium value*	8	11,1
While the concentration of $COCl_2$ gas has increased, the concentration of CO gas has decreased.	5	6,9
Nothing changes in the reaction.	9	12,5
Reaction decomposes as a substance was added.	2	2,8

In this question, the students are expected to answer that question as "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, press, concentration. When Table 4 is analyzed, it seen that most of the students interpret Le Chatelier's principle correctly. The ratio is: 19.4% of the students commented that the equilibrium is disturbed, 34.7% of them said the system will shift to side of consuming Cl_2 gas, 36.1% said the equilibrium will shift to products' side. When we look at the explanations of the students, we see that the students can interpret both the direction of the equilibrium and the change of the mole correctly:

"Added gas disturbs the equilibrium. Reaction will shift to 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.

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

It is understood from Table 4 that there are students who can explain the effect of concentration on the equilibrium correctly; however, answers that include misconceptions are available, too. 12.5%

of the students replied the question as "*nothing changes in reaction*."

SB13 from these students said:

"Nothing changes in reaction. Reaction remains unchanged."

This explanation shows that they could not understand the effect of concentration on equilibrium and apply the Le Chatelier's principle. Another misconception determined from the explanations of the student is their believing adding reactant would decompose the reaction. This opinion may have caused their thinking that reaction proceeds only in one direction at a time. Some of the answers that the students give about this topic are below:

"Perhaps the reaction decays because there are more Cl_2 molecules at equilibrium" SB18.

"Reaction decomposes as a substance was added" SA21.

At the same time, five questions (Questions 1, 2, 16, 17 and 21) in the CEMT are related to effects of concentration change on a system at equilibrium. One of them (Question 21) and frequency/proportion of students' responses for this question are given in Table 5.

Table 5. Question 21 in the CEMT and students' responses
(Tablo 5. KDKYT yer alan 21. soru ve öğrencilerin cevapları)

Consider the following reversible reaction that is in a state of equilibrium at a constant temperature,

$$H_2O(s) + SO_3(g) \rightleftarrows 2H^+(aq) + SO_4^{-2}(aq)$$

If some solid NaOH are added to equilibrium mixture, what can we say about this reaction? (OH^- reacts with H^+)

A) Concentration of H^+ increases because equilibrium shifts to product side.

B) Concentration of H^+ is constant because H^+ react with OH^- as a result of this, H^+ is consumed but this is counteracted by equilibrium shifts to product side

C) Concentration of H^+ is constant because addition of NaOH does not effect on equilibrium system.

D) *Concentration of H^+ decreases because H^+ react with OH^- as a result of this, H^+ is consumed but this is not counteracted by equilibrium shifts to product side.

E) Concentration of H^+ decreases because equilibrium shifts to reactant side.

	Category	f	%
Question 21	**SC**	27	17,9
	PC	36	23,9
	SM(b)	13	8,6
	SM(c)	12	7,9
	NR	63	41,7

Responses to this question showed that 8.6% of students believed that concentration change of substances at the equilibrium could be counteracted by equilibrium shift. In addition, 7.9% of students thought that addition of NaOH does not effect on equilibrium system. This result indicated that students could not understand correctly that concentration of H^+ decreases because NaOH reacts with H^+ and as a result of this, equilibrium shifts to products' side to minimize this effect.

- **Changing equilibrium conditions (increasing or decreasing temperature at the equilibrium):** The third interview question is related to increasing temperature at the equilibrium. This question and the categories belonging to third interview question (Table 6.) are presented below.

Question 3. What kind of changes happens in the system when we increase the temperature from 25 °C to 50°C?

Table 6. The categories belonging to third interview question
(Tablo 6. Üçüncü görüşme sorusuna ait kategoriler)

Student's View	Frequency (f)	Percentage (%)
Reaction will proceed to left to use up the added energy*	21	29,2
Reaction will shift to reactants*	31	43,1
While the concentrations of CO and Cl_2 gases increases, the concentration of $COCl_2$ gas decreases.*	8	11,1
Equilibrium is disturbed.	16	22,2
The rate of the reaction increases	16	22,2
Equilibrium constant (Kd) changes.	3	4,2
The rate of the forward reaction decreases.	2	1,4
No change happens in reaction.	3	4,2

In this question, effects of increasing temperature on exothermic reaction was purposed to determine and the students in the following percentages made true comments. 43.1% of the students expressed that reaction will shift to reactants; 29.2% of them said that reaction will proceed to left to use up the added energy, 22.2% of them said that the equilibrium is disturbed. Students who made explanations like that are given 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, concentration of CO and Cl_2 increase" SA1.

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

At the end of the interview analysis, it was found out that the students think that especially the temperature differently affect the forward and reverse reaction speed. This may result from their perceiving the "equilibrium direction" and "forward and reverse reaction speed" as the same. This can be seen from the students' answers:

"When temperature is increased, reaction wills shift to reactants. Because, rate of the reverse reaction will increase but and rate of the forward reaction will decrease." SA17

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

Students' having misconceptions coming from the previous units of chemical equilibrium unit was detected from the answers that the students gave to the asked questions. The striking of them is below:

"If temperature is increased, that means the energy is increasing. Activation energy goes up" SB22.

It is seen from that expression that the student did not understand the concept of activation energy exactly and has a misconceptions that the activation energy can change depending on heat.

Another significant explanation was made by student SC18:

"Boiling increases. More gas comes up into the air."

In this explanation, the student comments on the question as if it is a physical event far from the chemical equilibrium. Although all the substances in reaction are in gaseous state, the student's saying that there can be a boiling event shows that the student has misconceptions related to the boiling. One more important misconception was found out in student SB24's explanations:

"Temperature is increased. Molarities of all species in the reaction increase because molarity and heat are direct proportional" SB24.

As understood from that explanation, it is a completely wrong explanation and the student could not exactly form the molar concentration in his mind.

In addition to this interview question, there are five questions in the CEMT related to effects of temperature (Question 8, 9, 11 and 18). Question 11 and answers to this question are presented in Table7.

Table 7. Question 11 in the CEMT and students' responses
(Tablo 7. KDKYT yer alan 11. soru ve öğrencilerin cevapları)

The equilibrium between nitrogen dioxide gas and dinitrogen tetra oxide gas is as follows:

$$\underset{\text{(brown)}}{2NO_2(g)} \rightleftharpoons \underset{\text{(white)}}{N_2O_4(g)}$$

When temperature of the system is increased, color of reaction becomes darker. What can we say about the equilibrium reaction?

A) Number of moles at 50°C is less than at 20°C because reaction is exothermic and when temperature is increased, equilibrium position shifts to reactant side.
B) Number of moles at 50°C is less than at 20°C because reaction is endothermic and when temperature is increased, equilibrium position shifts to product side.
C) Number of moles at 50°C is more than at 20°C because reaction is endothermic and when temperature is increased, equilibrium position shifts to reactant side.
D) *Number of moles at 50°C is more than at 20°C because reaction is exothermic and when temperature is increased, equilibrium position shifts to reactant side.
E) Number of moles at 50°C is the same with at 20°C because temperature changes do not affect the system that is at equilibrium

	Category	f	%
Question 11	**SC**	26	17,2
	PC	35	23,1
	SM(b)	8	5,3
	SM(e)	12	7,9
	NR	70	46,4

As it is shown that in Table 7, students have misconceptions at rates of 5.3-7.9%. Especially, 7.9% of students believe that temperature changes do not affect the system that is at equilibrium. In addition, this misconception was identified in interview.

- **Changing equilibrium conditions (changes of volume and pressure at equilibrium).**

To determine students' understanding about the effect of volume change on chemical equilibrium system, the forth interview question was asked. Table 8. shows categories belonging to this question

Question 4. "What kind of changes happens in the system when the volume of the container is halved?"

Table 8. The categories belonging to fourth interview question
(Tablo 8. Dördüncü görüşme sorusuna ait kategoriler)

Student's View	Frequency (f)	Percentage (%)
Equilibrium is disturbed.	13	18,1
Reaction will shift to as to partially restore the original pressure*	19	26,4
Reaction will proceed to make fewer moles of gas*	23	31,9
Reaction will shift to products.*	16	22,2
While the mole of CO and Cl_2 gases decreases, mole of $COCl_2$ gas increases.	2	2,8
No change occurs in reaction.	8	11,1
Reaction decays	2	2,8

As can be seen clearly from Table 8, the following student-percentage made true explanations about the subject: 26.4% of the students who were interviewed said that the reaction will shift to as to partially restore the original pressure, 31.9% of them explained that reaction will proceed to make fewer moles of gas, 22.2F of them said that reaction will shift to products. Some of the students who explained their ideas like that are below:

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

"We look at the mole of the reactants and products. There are 2 gas particles on the left hand side of the reaction and 1 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.

Misconceptions were detected as well from the answers that the students gave. The common one of these is that volume change does not cause any alteration on equilibrium reaction. Some of these explanations are below:

"Nothing changes as there is a reaction between these chemicals. These substances are the components that are not affected by volume change" SB18.

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

It is clear from the explanations that the students make explanations that are far from pressure-equilibrium relationship.

Another misconception was detected in student SA17' explanation:

"There is the equivalence of air pressure with chemical pressure" SA17.

In this expression, even though there is an effort to construct a bridge between volume and pressure, air pressure has no relation with the subject. This result points out that the student has misconceptions coming from gases.

When students' answers are analyzed it seen that they try to explain the effect of volume change on pressure but use wrong concept even while doing this. Students' explanations that can exemplify the situation are below:

"Reaction will shift to side that has the most gas particles. More gas is produced" SB18.

"Gases are compressible, pressure is increased, reaction decays" SA20.

Questions 3, 4 and 15 in the CEMT were designed to determine students' understanding about effects of volume-pressure effects on equilibrium system. Question 15 and responses to this question are given in Table 9.

Table 9. Question 15 in the CEMT and students' responses
(Table 9. KDKYT yer alan 15. soru ve öğrencilerin cevapları)

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

$$aA_{(g)} \rightleftharpoons bB_{(g)}$$

When volume of the container was increased at a constant temperature, reaction shifted to 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 the relationship between a and b because moles of gases don't have any influence on equilibrium shift

	Category	f	%
Question 15	**SC**	32	21,2
	PC	34	22,5
	SM(c)	10	6,6
	SM(e)	12	7,9
	NR	53	35,1

As seen from Table 9, while most of the students' responses fell into NR (35.1%), PC (22.5%) and SC (21.2%) categories, significant percentage of students had misconceptions. 6.6% of students thought that when volume of the container was increased, equilibrium will proceed to make fewer moles of gases. This result was in accordance with the responses in the interview. In addition, another misconception "when volume of the container was increased, it cannot be estimated the relationship between moles of reactants and products, because these do not have any influence on equilibrium shift" was held by 7.4% of student.

In the last interview question, the students were supposed to describe Le Chatelier's principle in their own words. The categories belonging to this interview question are shown in Table 10.

Question 5. "What is Le Chatelier's Principle?"

Table 10. The categories belonging to fifth interview question
(Tablo 10. Dördüncü görüşme sorusuna ilişkin kategoriler)

Student's View	Frequency (f)	Percentage (%)
When a system at equilibrium is disturbed, the system will shift its equilibrium position in the opposite direction	22	30,1
Equilibrium system tends to compensate for the effects of disturbance.	12	16,7
It expresses how the system will reach equilibrium again when the equilibrium is disturbed	8	11,1
It states that when reagents are added or the temperature or pressure is changed at equilibrium, equilibrium position will shift to which direction.	7	9,7
It gives information about the reaction.	3	4,2
It is a chemical event	6	8,3
It explains the relationship of pressure-volume-mole in gases.	4	5,6
It is the balancing chemical equation	2	2,8

The more correctly the students state this principle, the more easily they will apply it on equilibrium reactions. Likewise, the coherence of the percentage of the students answering this question correctly with the percentages of the students answering the questions 2, 3 and 4 correctly proves that situation. Some of the students gave correct responses to that question, the percentages are like that: 30.1% of them said *when a system at equilibrium is disturbed, the system will shift its equilibrium position in the opposite direction*, 16.7% of them said, *and equilibrium system tends to compensate for the effects of disturbance.* 11.1% of them explained that it expresses *how the system will reach equilibrium again when the equilibrium is disturbed*. Some of the explanations are 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" SC24.

> "It is the stimulus-response theory. For instance, if the pressure of the equilibrium reaction increases, then the equilibrium position shifts to reduce the pressure or if a reactant is added, reaction shifts to products' side" SA8.

Besides these scientifically correct explanations, the incorrect ones are also striking. It is especially seen from these explanations that the students confuse Le Chatelier's principle with the other principles and laws in chemistry. 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" SA13.

"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 reactants" SB15.

"It explains molecular collision. It points out how chemical reactions take place. It states that in order for a reaction to proceed, the reactant particles must collide" SB12.

It is understood from the students' expressions that the students also confuse this principle with gas laws. Expressions of the students in this way are below:

"It is related to the gases. It is a principle about the pressure in container" SA20.

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

"I think it is one of the laws in gases" SA18.

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

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

"It determines the reactions between molecules" SC23.

"It is a principle about equilibrium mixture" SC11.

"I think it is related to enthalpy, namely ΔH. Enthalpy can be either positive or negative" SA13.

Table 11. The misconceptions identified in the CEMT
(Tablo 11. KDKT de saptanan kavram yanılgıları)

Misconceptions	Frequency (f)	Percentage (%)
When a solid substance is added to an equilibrium system at constant temperature, K_{eq} increases*.	11	7,3
When a solid substance is added to an equilibrium system at constant temperature, K_{eq} decreases*.	12	7,9
When a solid is added to system at equilibrium, concentration of solid increases.	9	5,9
Addition of the inert gas at constant pressure and temperature causes increase in partial pressure of reactants and products.*	8	5,3
Addition of the inert gas at constant volume and temperature causes increase in partial pressure of reactants	10	6,6
When tendency of maximum entropy is on products' side and tendency of minimum energy is on reactant's side, chemical reaction does not reach equilibrium*.	8	5,3
When tendency of maximum entropy is on reactant's side and tendency of minimum energy is on products' side, chemical reaction does not reach equilibrium*.	8	5,3
When the rate of reverse reaction is greater than forward one, chemical reaction reaches equilibrium	12	7.9

(*) shows the misconceptions which are originally found with this research

Table 12. The misconceptions identified in the CEMT
(Tablo 12. KDKT de saptanan kavram yanılgıları)

Misconceptions	Frequency (f)	Percentage (%)
When a catalyzer is added to equilibrium system, concentration of reactants and products changes	7	4,6
Temperature change does not affect equilibrium constant.	8	5,3
Only pure solids are included in equilibrium expressions*.	9	5,9
Only pure solids in the products' side and gases in the reactants' side are included in equilibrium expressions. *	8	5,3
Temperature changes do not affect the equilibrium system	12	7.9
When all reactants are consumed, the chemical reaction reaches equilibrium.*	11	7.3
When the volume of container is increased, the equilibrium proceeds to make fewer moles of gases	10	6,6
When the volume of container is increased, moles of reactants and products do not any influence on equilibrium shift	12	7.9
When a reactant is added to equilibrium system, concentration of the other reactants and products do not change	8	5,3
When a reactant is added to equilibrium system, K_{eq} increases	13	8,6
When a reactant is added to equilibrium system, K_{eq} decreases.*	11	7.3
At equilibrium, concentration of reactant increases because only reverse reaction occurs.	15	9,9
At equilibrium, concentration of reactant decreases because only forward reaction occurs.	10	6,6
When a catalyzer is added to equilibrium system, K_{eq} decreases.*	12	7.9
If a chemical reaction occurs in a series of steps, K_{eq} is calculated according to fast step.*	8	5,3
If a chemical reaction occurs in a series of steps, K_{eq} is calculated according to the slowest step.*	7	4,6

5. CONCLUSION AND SUGGESTIONS (SONUÇ VE ÖNERİLER)

The findings of this research show that although the students received an intensive classroom instruction on chemical equilibrium for four weeks, they still have misconceptions about the basic phenomenon and concepts of the chemical equilibrium. While some of these misconceptions are parallel to the ones in literature, some are detected for the first time in this research. A common misconception among students is that equilibrium is associated with everyday terms such as equality and balanced. Attributes of equality in general, equality of two sides, stability, and a static nature become associated with the concept of equilibrium [26]. Similar alternative conceptions were reported by Atasoy, Akkuş and Kadayıfçı [19], Özmen [27], Gussarsky and Gorodetsky [18, 28] Hackling and Garnett [15].

Description of chemical equilibrium as "*equalization of moles via molarity,*" "*transition from much to less*" and "*stabilization of temperature heat*" is found out for the first time in this study. In addition, "*when tendency of maximum entropy is on products' side and tendency of minimum energy is on reactant's side, chemical reaction does not reach equilibrium*", "*when tendency of maximum entropy is on reactant's side and tendency of minimum energy is on products' side, chemical reaction does not reach equilibrium*" and "*when all reactants are consumed, the chemical reaction reaches equilibrium*" *m*isconceptions were identified in this research.

Students also have problems about application of Le Chatelier's principle. Some misconceptions related to the effects of concentration change on a system at equilibrium were determined. One of them is that "when *one of the reactives is added to equilibrium mixture, the concentration of the added substance* remains the same." This result is consistent with the findings of by Hackling and Garnett [15]. Other misconception is that "*when one of the reactives is added to equilibrium mixture, only the concentration of the added substance changes*". Similar misconceptions have been reported previously [12]. Some misconceptions are originally found with this research. The misconceptions that we have not come across while reviewing literature are:

- Reaction decomposes as a substance was added.
- Only, reverse reaction is occurring.
- When a solid substance is added to an equilibrium system at constant temperature, K_{eq} increases.
- When a solid substance is added to an equilibrium system at constant temperature, K_{eq} decreases.
- When a reactant is added to an equilibrium system, K_{eq} decreases.

It was determined that the students have misconceptions about the effects of temperature change on a system at equilibrium. One of the misconceptions seen in the study that "*when the temperature of an exothermic reaction is increased, the rate of the reverse reaction decreases*". In the literature, Hackling and Garnett [15] reported a similar finding. Another misconception is that "*when the temperature of an exothermic reaction is increased, "boiling and activation energy increase"* identified for the first time in this study.

It seen that the misconceptions of students while explaining the effects of volume and pressure changes on equilibrium reaction are parallel to the findings of Voska and Heikkinen [21]. In the study carried out by Voska and Heikkinen [21], it was determined that "*change in the volume of the container doesn't affect the equilibrium shift* "which is held by 18% of the participants. The misconception which we have not come across while reviewing literature is that "*air pressure becomes equal with the pressure of the chemical substance*", "*addition of the inert gas at constant pressure and temperature causes increase in partial pressure of reactants and products*", "*addition of the inert gas at constant volume and temperature causes increase in partial pressure of reactants*".

From the findings, it was determined that student also hold new misconceptions about equilibrium constant. These are " *If a chemical reaction occurs in a series of steps, K_{eq} is calculated according to fast or the slowest step*", "*when a catalyzer is added to equilibrium system, K_{eq} decreases*", "*only pure solids are included in equilibrium expressions*", "*only pure solids in the products' side and gases in the reactants' side are included in equilibrium expressions*".

One of the most important outcomes of studies on students' misconceptions to alert teachers about students' difficulties in conceptualizing science knowledge. Teachers have a quite important role in preventing misconceptions. Teacher can help eliminate students' misconceptions. Before teaching a concept, the teachers should be able to check the literature to find out misconceptions that students may bring to class and which teaching methods are the best in correcting them. Such an approach would provide to teachers a chance to design better learning environment that help to develop concepts scientifically [29] In addition, in a study that had been done by Cheung[30], it was revealed that secondary school chemistry teachers did not have a deep understanding chemical equilibrium. Additionally, if chemistry teachers have difficulties in understanding chemistry topics or hold misconceptions about them, they cannot help their students to promote their conceptual changes. For this reason, studies on in-service chemistry teachers' understanding of chemistry topics should be conducted in Turkey as well as in that other countries. According to results of these studies, teachers should be informed about competency in subject matter with in-service training courses. Also, some studies show that traditional teaching strategies are ineffective to prevent misconceptions [9, 27, 31, 32 and 33]. Therefore, the subjects are abstract such as chemical equilibrium can be presented by alternative methods such as computer-assisted instruction, simulations, conceptual change strategies, analogy, and laboratory activities. Additionally, textbooks are very important information sources for students. Many researches showed that the textbooks used in schools have inadequate or sometimes incorrect information [34]. For this reason, textbooks used in schools should be analyzed by experts.

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