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Exploring Iranian pre-service teachers' conceptual understanding of chemical equilibrium

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ABSTRACT
This study aimed to develop a two-tier test to identify misconceptions of pre-service teachers about chemical equilibrium. The sample was made up of 135 pre-service chemistry teachers at Farhangian University in Iran (70 female and 65 male) who were spending the final semester of the eighth semester of the teacher training programme. After analysing the distribution pattern of the participants' answers in the first and second tiers, fifteen misconceptions were identified. A new misconception was identified for the first time, which we called the common ion effect which was held by about 50% of participants. Gender was a significant factor in the rate of misconceptions, with male pre-service teachers having fewer rate misconceptions compared with females. The results showed that when the first tier or the second tier was considered alone, female participants performed better, but when both tiers were combined, the performance of males was better. However, males had a weaker performance in three questions related to the approach to equilibrium in this situation. These findings will help educators plan their instruction by knowing pre-service teachers' preconceptions about chemical equilibrium.

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Introduction

Chemistry concepts are generated, expressed, taught, and communicated at three levels of representation: macroscopic, microscopic and symbolic. (Johnstone, 2000). The macroscopic level refers to the chemical processes most commonly seen with our senses. Microscopic refers to phenomena at the particle level (Talanquar, 2010), including the movement of electrons during bond breaking and bond-forming. We cannot observe any chemical changes that occur at this level. As a result, students find it hard to describe chemical phenomena at the microscopic level and tend to attribute the microscopic properties of matter to its macroscopic particles. (Ben-Zvi et al., 1988). Symbolic representations contain chemical symbols, equations, formulas, diagrams, models and animations (Siswaningsih et al., 2019). The ability to master the three levels of chemical representation makes chemistry so hard for students to learn. Therefore, learners often have difficulties explaining chemical phenomena with reference to these abstractions (Nur Akın & Uzuntiryaki-Kondakci, 2018; Yakmaci-Guzel, 2013). Submicroscopic and symbolic representations are abstract and cannot be experienced, so students have difficulty understanding these representations (Chandrasgaran et al., 2007; Griffiths & Preston, 1992). Students often have limited conceptual knowledge and little visual-spatial ability and cannot translate one representation into another (Keig & Rubba, 1993). For better conceptual understanding, it is important to help students see the connections between submicroscopic, symbolic and macroscopic representations (Gable, 1999).

The main goal of learning and teaching methods is to achieve meaningful learning (Üce & Ceyhan, 2019). Ausubel (2012) stated that to achieve meaningful learning, students need to make connections between new ideas, concepts and information, and prior knowledge they also need to make a linkage between concepts that are interrupted. When students learn more about chemistry, the range of the concepts they hold increases, the level of complexity of their concepts deepens, and their concepts are better integrated with each other (Taber & Watts, 1997). When learners encounter new ideas, they try to fit them into their existing schemas, and if they do not match, they try to either modify the present understanding or create a new understanding. Sheckley and Bell (2006) stated that the reflection process involves reinterpreting past experiences in the light of new experiences. If new experiences do not match pre-existing patterns, the brain makes sense of these experiences by making new connections from an alternative perspective.

Cognitivist and constructivist learning theories are two major theories of learning. Constructivism, which encompasses both cognitive and social dimensions, posits that learners actively construct knowledge through mental processes (cognitive constructivism) and through social interactions with others (social constructivism).These learning theories emphasise the role of prior knowledge and experience as the foundational structures that further knowledge builds upon. Constructivists view learning as an active process in which learners construct knowledge rather than passively absorb it (Waseem & Aslam, 2020). According to the constructivist view of learning, meaningful learning occurs when learners actively construct their knowledge by using existing knowledge to understand newly acquired experiences. Taber (2000) has stated that the first step in the constructivist learning approach is to inform the teacher and the student of the current ideas of the learner. Then, instruction is planned to challenge misconceptions, and teachers play a crucial role in providing students with opportunities for conceptual restructuring through thoughtful lesson planning. Teachers can help students eliminate their misconceptions by providing adequate knowledge and a clear understanding of these concepts.

According to constructivist theories, misconceptions formed by science students may be resistant to instruction. This resistance arises when new knowledge presented to students does not align with their previous experiences. In such cases, students try to replace the correct concepts by creating new concepts that better explain their experiences. No amount of instruction can help students change their conceptualisations until misconceptions are resolved by constructing new concepts (Bhola & Parchoma, 2015). Students' misconceptions interfere with subsequent learning. When the students are left to assimilate new information into their cognitive structure, these misconceptions hinder the integration of scientific knowledge. This causes a weak understanding or misunderstanding of the concept (Azizoglu et al., 2006). Thus, teachers should be aware of students' misconceptions and use appropriate educational methods to correct them.

In recent years, common alternative concepts held by students have been identified (Hakim et al., 2016; Jusniar et al., 2020; Suat et al., 2010; Tyson et al., 1999). Thus educators must understand their nature and source to be more effective in addressing those (Lamichhane et al., 2018). Unfortunately, the literature shows that teachers often have similar alternative conceptions to those of their students (Demircioglu et al., 2013; Hartelt et al., 2022) and can transfer their misconceptions to their students. Teachers' misconceptions are one of the sources of students' misconceptions. Identifying the chemical misconceptions in pre-service teachers and trying to eliminate them is very important during teacher training.

Literature Review

Ozmen (2004) reviewed some student misconceptions in chemistry such as those pertaining to mole concept, the nature of matter, bonding, molecules, chemical and physical changes, intermolecular forces, electrolysis, acids and bases, and chemical equilibrium. The nature of chemical equilibrium has been extensively studied at the secondary school and university levels since the 1960s, for example, in India (Banerjee, 1991), Spain (Quilez-Pardo & Solaz-Portoles, 1995), The Netherlands (van Driel et al., 1998), Australia (Tyson, et al., 1999), the US (Piquette & Heikkinen, 2005), Nigeria (Omilani & Elebute, 2020), Turkey (EyceYurt-Turk & Tuzun, 2021; Ozmen, 2008), China (Cheung, 2009) and, Malaysia (Karpudewan et al., 2015). Nowadays teaching chemical equilibrium takes up a large part of the chemistry curriculum (Doymus, 2008). Chemical equilibrium involves mathematical calculations, and graphing. To understand chemical equilibrium, students must be familiar with other related conceptions, including concentration, stoichiometry, states of matter, and the mole. Chemical equilibrium is required to understand other conceptions in chemistry (Kaya, 2013) such as oxidation-reduction, acids and bases, phase changes, reaction rate, and solubility (Karpudewan et al., 2015; Voska & Heikinnen, 2000). In addition, chemical equilibrium requires representations at the macro, micro and symbolic levels (Yıldırım et al., 2011). But chemical equilibrium is a difficult concept for both teachers and students due to its abstract nature and the use of inappropriate didactic approaches (Bernal-Ballen & Ladino-Ospina, 2019; Kurniawan et al., 2020; Aydeniz & Dogan, 2016). As a result, students at all levels of education hold misconceptions or alternative conceptions related to chemical equilibrium (Demircioglu et al., 2013; Voska & Heikinnen, 2000; Cakmakcı et al., 2006).

Identifying student misconceptions is a significant step in the learning process (Ghirardi et al., 2015; Prodjosantoso, 2019). Teachers should monitor students' understanding of scientific principles and develop teaching strategies to correct any wrong ideas. One way to find the misconceptions is to use a diagnostic test. Multiple-choice questions are suitable for statistical analyses due to their ease of administration, objective marking, and low cost effectiveness (Wuttiprom et al., 2009; Seni & Yilmaz, 2017) Sometimes the students may give correct answers to the chemical equilibrium questions, but they are not unable to provide correct reasons (Quiliz-Pardo & Solaz-Portoles, 1995). Therefore, a two-tier multiple-choice diagnostic test is helpful to teachers with an easy-to-administer pencil and-paper test designed to recognize alternative concepts of students. Two-tier multiple-choice tests can help teachers to determine reasons for misconceptions among the students, obtain the ratio of frequency in students, and the teachers' being aware of these alternative concepts (Cullinane, 2011; Tyson et al. 1999).

Several chemical equilibrium alternative conceptions reported in the literature (e.g., García-Lopera et al., 2014; Karpudewan et al., 2015; Omilani & Elebute, 2020; Satriana et al., 2018). Van Driel and Graber (2003) catalogued these alternative conceptions into five categories: (a) confusion of amount (moles) with concentration—for instance, the student tries to calculate concentration when given molarity; (b) confusion over the appearance/disappearance of material—for instance, the student mistakenly assumes the reverse reaction starts when the forward reaction has been completed; (c) erroneous interpretation of the equilibrium constant, K—for instance, the student mistakenly assumes that the value of the equilibrium constant changes according to the amounts of reactants or products; (d) erroneous in the application of Le Chatelier's principle—for instance, the student tries to adjust a system formerly at equilibrium; (e) misconceptions about gaseous systems—for instance, the student assumes that gaseous equilibrium can be achieved in an open container; and (f) other alternative concepts, including dynamism versus staticity—for instance, the student is unable to understand the nature of a system at dynamic equilibrium (Piquette & Heikkinen, 2005). Ozmen (2008) identified four categories of students' common alternative conceptions regarding chemical equilibrium, including the approach to equilibrium, application of Le Chatelier's principle, the equilibrium constant, and heterogeneous equilibrium. Later, Karpudewan et al. (2015) mentioned the following as alternative concepts related to chemical equilibrium: (a) the forward reaction rate enhances continually from the beginning of the reaction until the reaction reaches equilibrium; (b) the existence of a simple relationship between the concentration of reactants and products; and (c) when a change is made to a system at equilibrium (e.g. adding a reactant), the rate of the 102 forward reaction increases while the rate of the reverse reaction decreases.

Several researchers (Banerjee, 1991; Cheung (2009); Ozmen, 2008; Piquette & Heikkinen, 2005; Quílez-Pardo & Solaz-Portolés, 1995) have studied how Le Chatelier’s principle affects teacher's understanding of the effects of addition of more reactants or products on chemical equilibrium. Studies have shown that pre-service teachers may hold misconceptions about basic science concepts (Demircioglu et al., 2013). But what are the main misconceptions of pre-service chemistry teachers, and is there a significant difference between the level of understanding and the type of misunderstandings of male and female teachers in this field or not? To our knowledge, studies about pre-service chemistry teachers’ chemical equilibrium misconceptions were limited.

A few studies have explored pre-service teachers' misunderstanding of chemical equilibrium. Recently, EyceYurt-Turk and Tuzun (2021) highlighted twenty Turkish pre-service science teachers’ images and misconceptions about chemical equilibrium. Their study had beneficial information but did not include many important concepts of chemical equilibrium. It did not investigate the possible difference in chemical equilibrium understanding between male and female teachers.

Objectives of the Study and the Research Questions

Pre-service teachers must have a firm foundation in chemical equilibrium concepts. Therefore determining the chemical equilibrium misconceptions is very important (Mai et al., 2021; Eyceyurt-Turk & Tuzun, 2021). Teachers are the most important source of creating misconceptions in students. Pre-service teachers are future teachers; if they have misconceptions, their students will also have misconceptions. To avoid forming misconceptions in students, educators should be informed about pre-service teachers’ misconceptions and try to construct the correct chemical equilibrium concepts for them. The results of such studies can help researchers, teachers, and teacher educators to develop new alternative teaching techniques to change and / or to prevent students' misconceptions The instrument used in this research that was adopted from previous studies or developed by the authors will increase the research literature with conceptual items in the chemical equilibrium area that could be referred to by other researchers. The main objective of this research was to explore the chemical equilibrium misconceptions of pre-service chemistry teachers at Farhangian University. Farhangian University is responsible for training teachers in Iran. The model of teacher education used in Farhangian University through which prospective chemistry teachers may enter the profession involves a four-year programme in chemistry and education i.e. the concurrent subject matter/professional training model. If student teachers' misconceptions are not directly addressed, they may persist throughout the four-year training programme and even beyond. An exploratory study was carried out to identify the chemical equilibrium misconceptions of a group of pre-service chemistry teachers in their fourth year of study with gender as a possible source of variation.
The research questions were

1- What chemical equilibrium misconceptions do these 4th-year pre-service chemistry teachers hold?

2. Is there a link between these misconceptions and gender?

Methods

Research Design

This research was of the survey type. To diagnose pre-service teachers’ misconceptions of chemical equilibrium, a 20-item two-tier multiple choice test was developed. The analysis of the pre-service teachers’ misconceptions was carried out by looking at the pattern of participants' answer distribution on the first and second tiers. The answer patterns in the second tier, which are the reasons for the student's answers can be used as the basis to determine the participants' alternative conception. In order to find out the type of pre-service teacher's misconceptions, each option that the participants had chosen was carefully examined, and the type of misconceptions that led to the selection of each option was extracted. In other words, these results were used to elucidate pre-service teachers' conceptual understanding of chemical equilibrium concepts. The found misconceptions were coded and finally, types of misconceptions were extracted. Independent *t*-testing were used to obtain the results. The independent sample t-test (group t-test) is performed when the samples typically consist of an independent population. (Liang, Fu, & Wang, 2019). Inferential statistical tests are associated P value. In a 95% confidence interval, $P > 0.05$ in each research variable shows that the null hypothesis was not rejected, and no significant differences between the two groups were observed.

Participants

The population of this study covers all the pre-service chemistry teachers of Farhangian University. These teachers were in the fourth year of the teacher training programme and preparing to become high school chemistry teachers for Grades 10 to 12. Previously, they had completed most of their courses on the subject matter (chemistry) and pedagogy (learning theories, teaching methods, educational psychology, classroom management, material development, etc.). The research population consisted of 205 individuals, and based on the Cochran formula, 135 of them were selected as the statistical sample. 65 of the participants were male and 70 were female. The age range of the participants was between 21.0 and 24.8 years. There was no significant difference between the two groups of teachers in terms of demographic features. The selection criteria of the participants were their willingness for the study. All participants had the right to leave the study at any time. Also, all participants were anonymous, and based on research ethics codes were used instead of their names.

Instrument

The test items were selected from previous studies done by Ozmen (2008), Tyson et al. (1999), Cheung et al. (2009) and Karpudewan et al. (2015) with minor revisions. The final questionnaire was prepared in the primary language and then translated into the Standard English language. Two-tier-multiple-choice tests often have been used to determine alternative conceptions of students in science education. The first tier of each question has four choices used to recognise the chemical equilibrium knowledge of students; the second tier involves four possible reasons containing three wrong reasons and one right reason for the question posed in the first tier. The second tier is based on an alternative conception held by students. The questionnaire was classified into five categories consisting of the *equilibrium constant* (4 questions), application of *Le Chatelier's principle* (9 questions), *heterogeneous equilibrium* (2 questions), the *effect of a catalyst* (2 questions), and *approach to equilibrium* (3 questions). The reliability of this questionnaire was calculated using Cronbach's alpha coefficient. Cronbach's α values for each category of five chemical equilibrium categories ranged from 0.775 to 0.861. The content validity of the questionnaire was evaluated by three expert chemistry instructors who taught similar students. The experts were asked to evaluate the questions based on relevance, clarity, simplicity, ambiguity and scientific accuracy (Yaghmaie, 2003). The participants' responses were analysed and classified into three forms understanding, not understanding, and misconception (Table 1). Data were analysed statistically using an independent t-test. The software used was SPSS 26, and the significance level was 95 %. In the next step, responses were analysed to find misconceptions.

Table 1

Categories of Two-Tier-Multiple -Choice Test

Student' Answers		Level of understanding
First Tier	Second Tier	
True	True	Understanding
True	False	Misconception
False	True	Misconception
False/No Answer	False/No Answer	Not Understanding

Question 8, as shown in bellow box, was one of the questions that drew the lowest number of correct answers. This question, which was on the application of the *Le Chatelier's principle*, was designed to evaluate the impact of the conceptual understanding of concentration change on the direction of equilibrium.

Question 8: If you have a 0.5 M solution of sodium dichromate ($Na_2Cr_2O_7$) in which the following equilibrium is established

$2CrO_4^{2-}{}_{(aq)} + 2H^+(aq) \leftrightarrows Cr_2O_7^{2-}{}_{(aq)} + H_2O_{(l)}$

yellow orange

and you add 10 mL of 0.5 M solution of sodium dichromate to the original solution what would you observe?

(a) the solution becomes yellow
(b) the solution becomes deeper orange
(c) *the solution remains unchanged

Reason

(1) to counteract the increased amount of $Cr_2O_7^{2-}{}_{(aq)}$ the system will form more $CrO_4^{2-}{}_{(aq)}$
(2) there will be more collisions between particles of $Cr_2O_7^{2-}{}_{(aq)}$ and $H_2O_{(l)}$
(3) *there is no change in the concentration of any species
(4) because of increase in $Cr_2O_7^{2-}$, Q will be greater than K_{eq}

Results & Analysis

The overall performance of pre-service chemistry teachers in all concept areas except *the application of Le Chatelier's principle* in the female group was greater than 50 %. The highest overall average score was related to *the approach to equilibrium*, while *the application of Le Chatelier's principle* has the lowest overall average score. Males left more questions unanswered than females (Table 2).

Table 2

Mean Scores for Each Chemical Equilibrium Categories in Instrument

Equilibrium categories	Questions	% Average score		% No Answer	
		female	male	female	male
Equilibrium constant	Q1, Q4, Q7, Q9	74.6	73.1	0.0	1.5
Application of Le Chatelier's principle	Q8, Q9, Q10, Q11, Q12, Q14, Q15, Q16, Q20	43.5	50.3	2.8	6.1
Heterogeneous equilibrium	Q2, Q6	63.6	64.6	0.0	1.5
Effect of a catalyst	Q3 , Q13	52.1	50.0	1.4	6.1

Approach to equilibrium	Q5, Q17, Q18	81.4	78.0	1.4	7.7
All categories		58.3	60.4	1.6	4.9

Table 3 presents the independent t-test to investigate the effect of gender on the performance of pre-service chemistry teachers in equilibrium concepts. The results showed that there was not a significant difference in the performance of the female and male participants in terms of the application of Le Chatelier's principle, the heterogeneous equilibrium, and the catalyst effect ($p \geq 0.05$) at 95% confidence interval. However, there was a significant difference in the *equilibrium constant* and the *approach to equilibrium* between the two groups ($p < 0.05$). However, the performance of pre-service chemistry teachers in all equilibrium categories in male and female participants was found to be 3.13 and 3.25, respectively [$t(133) = 3.642$; $P > 0.05$]. According to these findings, it can be argued that there is no significant difference between the performance of male and female pre-service chemistry teachers in terms of all equilibrium categories.

Figures 1 to 3 illustrates the performance of female and male pre-service chemistry teachers for each question in the Equilibrium Misconceptions Identification Instrument in the first tier, second tier, and both tiers, respectively. As can be seen in Figure 1, the poorly answered question in the first tier on the instrument, with less than 10.0 % in both groups, was Question 8. In addition to question 8, the percent of correct answers of prospective men teachers for the first tier in questions 3, 16, and 20 was less than 50.0 %, while females had a similar situation only in questions 20 and 16. In general, female pre-service teachers performed better in answering the first tier of instrument questions. The only question where males' performance was higher than females' is question 2, which is in the category of *heterogeneous equilibrium (see Table 2).* In questions 4, 8, 9, 11, 16, and 19, both males and females had almost the same performance, and in other questions, the percent of females' correct answers was higher. The biggest difference is related to question 18, which is in the category of *approach to equilibrium*.

When considering the correct reason (the second tier) for each question, Questions 8 and 20 exhibited correct answer frequencies below 10 % (Figure 2). These questions are concerned with the effect of concentration change on the direction of equilibrium in the category of *application of Le Chatelier's principle*. The highest difference in the correct answer in the second tier is related to question 18 (72.85 % of females versus 47.70 % of males). In questions 1, 2, and 8, the two groups had almost the same answer. Prospective men teachers performed slightly higher than females only in questions 7, 14, and 20, and in the other questions, the performance of female pre-service teachers was better.

Table 3

The Results of the Independent T-Test and the Comparison of Each Equilibrium Category As Well As All Equilibrium Categories in Male and Female Experimental Groups

Equilibrium Categories	Gender	Mean	SD	t	df	*p*-value
Equilibrium constant	Male	3.65	0.55	1.184	133	0.021
	Female	3.76	0.37			
Application of Le Chatelier's principle	Male	2.61	0.29	2.296	133	0.622
	Female	2.70	0.29			
Heterogeneous equilibrium	Male	3.50	0.74	0.430	133	0.974
	Female	3.52	0.77			
Effect of a catalyst	Male	3.59	0.95	1.932	133	0.456
	Female	3.79	0.89			

Approach to equilibrium	Male	3.47	0.60	3.510	133	0.000
	Female	3.65	0.41			
All categories	Male	3.13	0.27	3.643	133	0.053
	Female	3.25	0.21			

As seen in Figure 3, by considering correct answers for two-tier, in addition to questions 2, 8 and 20 in female and male groups, the correct answer rate to question 16 for female teachers decreased to 25 %. Also, the rate of correct answers to questions 11 and 14 dropped sharply in the female group. The performance of males and females in questions 1, 3, 4, 9, 13, and 19 were almost similar, while female pre-service teachers had a higher percent of correct answers for both tiers in questions 5, 12, 15, 17, and 18. Males performed better in other questions. The interesting point is that among the 5 questions that the performance of female pre-service teachers was higher, three questions 5, 17, and, 18 belong to the category of approach to equilibrium. Therefore, it can be concluded that the level of misconceptions related to this category was higher among male pre-service teachers than among females. A complete list of identified misconceptions can be found in Table 4.

Figure 1

Comparison of Performance of Female and Male Pre-Service Chemistry Teachers for the First Tier of Each Question in the Instrument

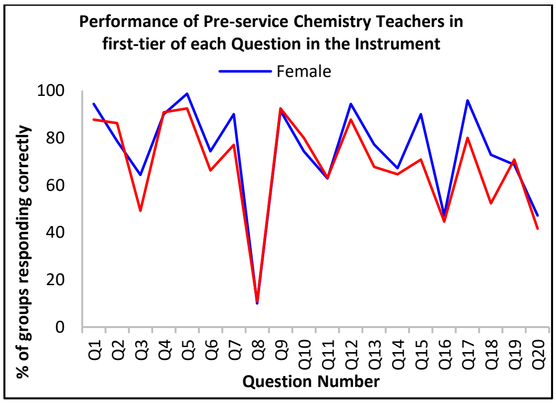


Figure 2

Comparison of Performance of Female and Male Pre-Service Chemistry Teachers for the Second Tier of Each Question in the Instrument

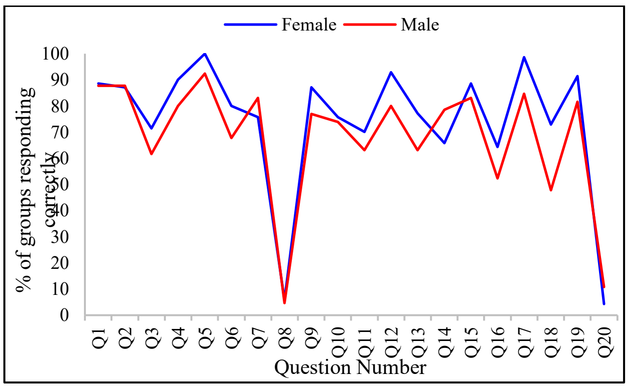
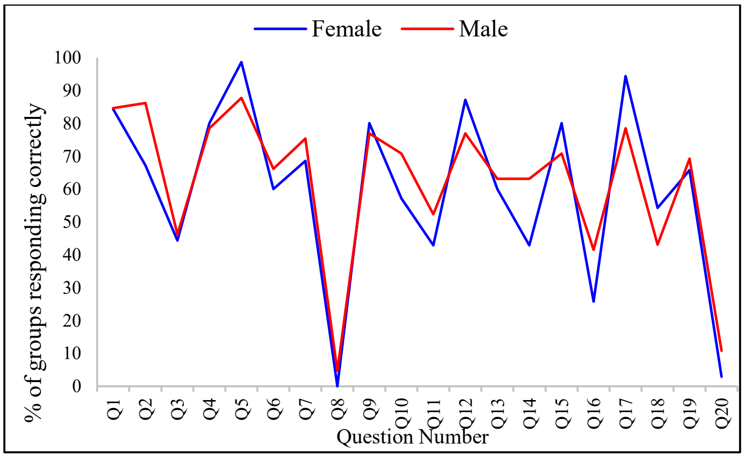


Figure 3

Comparison of Performance of Female and Male Pre-Service Chemistry Teachers for the Both Tier of Each Question in the Instrument



Fifteen alternative conceptions were identified and listed in Table 4. Similar types of students' alternative concepts have been reported in the literature (Karpudewan et al., 2015; Omilani & Elebute, 2020; Satriana et al., 2018; Sendur et al., 2011; Voska & Heikkinen, 2000).

Table 4

The Percentages of Students' Alternative Conceptions

Concept Area	Subtopic	Misconceptions	% sample		
			female N = 70	male N = 65	Total N = 135
Equilibrium constant	Dependence of the equilibrium Constant to the temperature	With decreasing the temperature in an exothermic reaction, fewer products are produced, and consequently, the Keq decreases.	20.0	13.8	17.1
	Constancy of the Concentrations in equilibrium	The higher initial concentrations of the reactants increased the numerical value of Keq.	28.6	9.2	19.3
	Constancy of the equilibrium constant	Keq and the concentration of the reactants changes in the equilibrium state.	42.8	20.0	31.8
Application of Le Chatelier's principle	The effect of temperature on the direction of equilibrium	As temperature increases, more products are formed.	18.6	16.9	17.8
		When the temperature is changed, whether the reaction is endothermic or exothermic does not affect the direction of the equilibrium shift.	14.3	12.3	13.3
	The effect of pressure and volume on the direction of equilibrium	As the volume increases (pressure decreases), the reaction moves towards the production of fewer gaseous moles.	22.8	21.5	22.2
		Pressure affects all reactions containing gaseous substances, whether the reaction has an equal or different number of gaseous substances on both sides.	18.6	12.3	15.5
		Pressure does not affect reactions containing gaseous substances.	60	13.8	37.8
	The effect of common ion on the direction of equilibrium	The addition of a substance containing common-ions does not affect the direction of equilibrium.	61.4	36.9	49.6
	The effect of concentration change on the direction of equilibrium	When a substance is added to an equilibrium mixture, the equilibrium will shift to the side of the addition.	94.3	38.5	67.4
Heterogeneous equilibrium	Study of Heterogeneous equilibrium	Le Chatelier's principle may apply to any system, including heterogeneous equilibrium systems.	65.7	1.5	34.8
Effect of catalyst	Effect of catalyst on the equilibrium	The rates of the forward and backward reactions could be affected differently when the catalyst was added.	47.1	15.4	31.8
		Catalysts cause an increase in product concentration.	34.3	7.7	21.5
Approach to equilibrium	Calculation of equilibrium concentrations	Equilibrium reactions continue until all the reactants are consumed.	28.6	16.9	23.0
		At equilibrium, concentrations of reactants and products are equal.	11.4	4.6	8.1

Discussion and Conclusion

In the current study, we used a two-tier multiple choice diagnostic test to identify chemical equilibrium misconceptions in pre-service chemistry teachers of Farhangian University in Iran Teachers do not have to construe the intention of students who cannot clearly explain their reasoning. Its results can be used to draw up a conception profile that maps a particular student's identified conceptions. Such profiles help teachers to identify a range of misconceptions that need to be corrected (Voska, 2000).

The current study focused on chemical equilibrium misconceptions. The content of chemical equilibrium is abstract, complicated, and has a high degree of connection with other content areas of chemistry. Teachers and students may tend to overlook the specific nature of the chemical equilibrium content and simplify their interpretation of related problems (Tyson et al., 1999). This can lead to the formation of misconceptions in them.

In this study, the misconceptions related to chemical equilibrium are classified into five categories: *equilibrium constant*, *application of Le Chatelier's principle*, *heterogeneous equilibrium*, *effect of a catalyst*, and *approach to equilibrium*. The student teachers generally performed well. However, the results also showed that they exhibited several misconceptions about chemical equilibrium concepts, and fifteen misconceptions were identified. As shown in Table 4, the percentage of observed misconceptions for all participants varied between 8.1 and 67.4%. These findings are consistent with the results of other studies (Voska & Heikkinen, 2000; Omilani & Elebute, 2020; García-Lopera et al., 2014; Ozmen, 2008). The percent of misconceptions varied between 11.4 % to 94.3 % for females and 1.5 % to 38.5 % for male pre-service teachers.

The most significant misconceptions revealed by this study fall in the *application of Le Chatelier's principle* category, as follows:

1- *When a substance is added to an equilibrium mixture, the equilibrium will shift to the side of the addition* in the subtopic of *the effect of concentration change in the direction of equilibrium*. This misconception held by 67.4 % pre-service chemistry teachers (94.3 % of females and 38.5 % of males). This misconception is due to an over-emphasis on the 'change-then-minimize' logic of Le Chatelier's principle in the Chemistry Curriculum and textbooks (Cheung et al., 2009; Yamtinah, 2019).

2- The addition of a substance containing common-ions does not any affect the direction of equilibrium in the subtopic of the effect of common ion on the equilibrium direction, which held by 49.6 % pre-service chemistry teachers (61.4 % of females and 36.9 % of males).

The study revealed that the lowest percent of misconceptions among prospective teachers were observed concerning two key concepts:

1- *At equilibrium, concentrations of reactants and products are equal* which held by 8.1 % of prospective teachers (11.4 % of females and 4.6 % of males).

2- *The temperature changes, does not effect on the direction of the equilibrium, whether the reaction is endothermic or exothermic* which held by 13.3 % of prospective teachers (14.3 % of females and 12.3 % of males).

One reason for these observations can be the instructional approaches used in teaching these chemical equilibrium concepts, which need more research.

This study revealed a new misconception: "the common ion has no effect on the direction of equilibrium" had not been exposed and investigated as a separate misunderstanding in previous studies. The common ion effect occurs when a given ion is added to an equilibrium mixture that already contains that ion and the position of equilibrium shifts away from forming more of it. To the best of our knowledge, the common ion effect as a separate issue in chemical equilibrium misconception has not been investigated in the literature so far. In the present study, we observed that nearly 50 % of pre-service teachers (61.4 % females and 36.9 % males) had problems understanding the effect of adding a substance containing common ions to the equilibrium mixture. This misconception ranks second among the fifteen misconceptions found in this research.

The interesting point is that the correct answers to most of the questions in the first tier and second tier were higher in the female pre-service teachers (Figures 1 and 2). The results of the answers to the first tier of questions showed that female pre-service teachers had a higher correct answer rate only in question 2. Question 18, which is in the category of approach to equilibrium, showed the highest difference in the performance between males and females (Figure 1). As in the first tier, in the answer to the second tier, the highest difference in the correct answer was related to question 18. Also, only in three questions 7, 14, and 20 did men perform slightly better (Figure 2). But when both tiers were combined, the results for the males were better (Figure 3). These findings agree with Table 2, which shows that male participants overall held fewer misconceptions than females. But, the overall rate in the case of *not understanding* of chemical equilibrium concepts in pre-service male teachers was higher than female participants (4.9 % vs. 1.6 %). On the other hands, Female pre-service teachers had better performance in only five questions, 5, 12, 15, 17, and 18. It is interesting to know that among these questions, three questions 5, 17, and 18 together forms the *approach to equilibrium* category and it is interesting that male pre-service teachers had a lower performance than females in all questions of this category.

As can be seen in Table 4, in some of the identified misconceptions, the observed difference between male and female participants is significant. For example, in the category of *heterogeneous equilibrium*, the percent of observed misconceptions in the males had the lowest amount of identified misconceptions in this research (only 1.5 %). While in the case of females, the percent is very high (65.7 %), and has been assigned the second rank of observed misconceptions in this research.

Because male and female teachers are trained in Farhangian University (Teacher Training University of Iran) in separate faculties, so we investigated the effect of gender on the rate of misconceptions in pre-service chemistry teachers in detail. The results showed that male subjects exhibit lower rates of misconceptions and also a higher rate of not understanding. Females and males showed significant differences in the terms of the equilibrium constant and the approach to equilibrium, which demonstrated that males showed better comprehension of these concepts than females. According to Table 4, the gender of participants has an important effect on the rate of misconceptions held by pre service chemistry teachers. The literature shows that when gender differences are studied in explaining scientific phenomena, Female pre-service teachers had more misconceptions than males in most countries (Harmala-Brasken et al., 2020, Sheehan et al., 2011). Boys, on average, have a greater ability to recall and apply their knowledge of science and identify and generate models and predictions based on the models (OECD, 2016). Kaufman (2007) and Soeharto & Csapó (2022) stated that males on average are better able to visualise submicroscopic levels of chemistry concepts, which is due to their better spatial ability compared to females. This ability of men, in turn, can be an advantage for conceptual understanding of submicroscopic levels of chemistry concepts. Thus, female pre-service teachers exhibit more misconceptions than males. This finding may be due to different learning strategies used by female learners. Sheehan et al. (2011) found that the number of chemistry misconceptions was higher in Irish pre-service female teachers. Meece and Jones (1996) found that female learners were more likely to engage in rote learning. According to Sheehan (2010), the differences in the number of misconceptions held by the genders may be the consequence of differences in cognitive development, so male students at upper secondary and university levels are more likely to operate at the formal operational level than female students.

One of the most essential conclusions of research on pre-service teachers' misconceptions is to inform educators about pre-service teachers' difficulties in understanding science knowledge. Teachers have a significant role to prevent students' misconceptions and can help to eliminate their misconceptions. Before teaching a chemical concept such as chemical equilibrium, teachers should be able to review the literature to find out alternative conceptions that students may bring to class and which teaching strategies are the best to correct them (Sendur et al., 2011). If chemistry teachers have problems understanding the chemistry concepts or have misconceptions about them, they cannot assist their students to resolve their conceptual difficulties. Therefore, the teachers themselves must have a deep understanding of chemical concepts and have no misconceptions.

One of the other important goals related to this study is to pay attention to the preparation process of prospective chemistry teachers. It is necessary to improve the preparation and professional development of pre-service chemistry teachers by discovering and identifying common chemical equilibrium alternative concepts and trying to modify them.

These findings may help chemistry educators ameliorate pre-service teachers' understanding of one of the important and complex topics of chemistry named chemical equilibrium (Piquette and Heikkinen, 2005).

This study reported several misconceptions in prospective chemistry teachers. The fact that individuals who hold these misconceptions are pre-service teachers makes the findings considerable. Teachers should have a proper understanding of science concepts before they can help students learn these science concepts. Prospective and in-service teacher training programs should emphasise the significance of conceptual problem-solving and supply opportunities for pre service and in-service teachers to inform their own understanding of science concepts.

Identifying of pre-service teachers' misconceptions about chemistry concepts can be effective in improving chemistry education and learning. Teachers around the world are always faced with the challenge of identifying and changing students' misconceptions, so it is necessary to teach those techniques to identify misconceptions and how to change concepts during the Teacher Training Program (Valanides et al., 2003). Valanides et al. (2003) pointed out changes in chemistry education, including chemistry curricula and textbooks, as well as teacher training programmes as solutions in this field. We hope that the results of this research will help design teaching approaches that can enhance pre-service teachers' conceptual understanding of chemical equilibrium concepts.

Recommendations

Based on the above findings and conclusions, the following recommendations are made:

1. Before teaching chemical concepts, including chemical equilibrium, educators should review the literature to identify alternative concepts that pre-service teachers may bring to the classroom and find appropriate instructional strategies to modify them.
2. Before teaching the lesson, the teachers should use a initial assessment to identify the misconceptions of the pre-service teachers on the topic of chemical equilibrium (students are told the test 'doesn't count').
3. Instructional approaches in teaching chemical equilibrium concepts should be investigated to determine if there is a relationship between instructional approaches and the rate of misconceptions observed.
4. The contents of textbooks should be examined to determine their possible impact on the development of misconceptions related to the concepts of chemical equilibrium.

Ethics Approval and Consent to Participate

All participants in this research were anonymised. Informed consent was obtained verbally before participation. All participants consented to their participation in this study.

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