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Misconceptions in Rate of Reaction and their Impact on Misconceptions in Chemical Equilibrium

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Abstract: Descriptive correlational research was conducted to discover misconceptions on Rate of Reaction (RR) that impact on Chemical Equilibrium (CE) misconceptions. This research was conducted to 245 eleventh-grade students of High School in Gowa, South Sulawesi, Indonesia, that having been studied the RR and CE topics. Misconceptions data were collected using three-tier tests and semi-structured interviews. The data were analyzed using descriptive and correlational analysis. Description of RR misconceptions that impact on CE misconceptions are determined with the percentage of students who consistently experience misconceptions about RR and CE. There were six misconceptions in RR that have an impact on CE, which are: Misconceptions related to changes in the reaction rate with time; The effect of temperature on the rate of reaction; The effect of adding catalysts to the activation energy; and the mathematical relationship between the rate of reaction and the number of moles. Misconceptions in RR and misconceptions in CE having a correlation coefficient, using Spearman's formula, of 0.39. These results indicate that the impact of misconception in RR on CE is moderate. This study suggests that education practitioners should eliminate the misconception of prerequisite concepts before teaching the next related concepts.

Keywords: *Impact, misconception, rate of reaction, chemical equilibrium.*

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Introduction

Concepts in chemistry were hierarchically built from basic (O'Connor, 2015; Seery, 2009). Therefore, students' mastery of prerequisite concepts would be an important variable in chemistry learning which can either help or hinder their understanding of the next related concepts (Ambrose et al., 2010; Carey, 2000; Sing & Brod, 2016). In essence, new knowledge "sticks" better when it has a prerequisite concept or prior knowledge to stick to (Ambrose et al., 2010, p. 13). During the learning, students tend to form perceptions consistent with the results of their previous study (Osborne & Wittrock, 1983). They are required to have proper understandings of the prerequisites concepts to be able to comprehend higher-level materials (Effendy, 2002). Otherwise, they would not be able to make connections ended up having trouble understanding the new concept (Taber, 2009). A learner's prior knowledge is the most important variable tobe successful in learning science. If the students' prior knowledge is not enough to process new information, they will become confused, reason inaccurately, and eventually form a misconception (Bilgin & Uzuntiryaki, 2003).

The students need to have prior knowledge about the Rate of Reactions (RR) before learning Chemical Equilibrium (CE) (Ganasen & Shamuganathan, 2017). Concepts in (RR) including the forward reaction, reverse reaction, and rate of reaction are prerequisites for some concepts in (CE), such as concepts of equilibrium constants *K, Kp,* and *Kc* (Garnett et al., 1995). Meanwhile, *K* and *Kc* concepts are related and fundamental to several subsequent ideas, such as Acid-Base Equilibrium, Hydrolysis, and Solubility topics (Voska & Heikkinen, 2000).

Understanding a concept requires integrations of three representations: macroscopic, submicroscopic, and symbolic (Dhindsa & Treagust, 2014; Voska & Heikkinen, 2000). A submicroscopic description is a conceptual level used to explain macroscopic phenomena, which will later describe the more abstract particulate level chemical phenomena (Dhindsa & Treagust, 2014; Johnstone, 2000; Stojanovska et al., 2017; Talanquer, 2011). Understanding these three

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levels of representation is essential to comprehend chemical phenomena, including RR and CE, that involve mathematical equations, algorithmic abilities, and interpretations (Cook et al., 2008).

Concepts in RR and CE are mostly abstract ones. The involvement of representations in RR and CE makes these topics tend to be difficult to understand by students. This difficulty can cause students to experience errors in understanding a concept. This situation, if occurred consistently, would potentially lead to misconceptions (Barke et al., 2009; Nakhleh, 1992; Ozmen, 2008), or also called alternative concepts (Taber, 2009; Tyson et al., 1999) or spontaneous knowledge (Horton, 2007).

Some researchers have reported several misconceptions about CE. Some of them are as follows; The forward reaction rate becomes faster at equilibrium (Hackling & Garnett, 1985); The state of equilibrium occurs when the concentrations of the reactants and products remain the same (Barke et al., 2009; Hackling & Garnett, 1985; Nakhleh, 1992; Yakmaci-Guzel, 2013); The increase in temperature causes the forward reaction rate to decrease and the reverse reaction rate to increase (Barke et al., 2009; Bilgin & Uzuntiryaki, 2003; Hackling & Garnett, 1985); On the equilibrium, reactions will no longer occur (Nakhleh, 1992). Equilibrium is a static process (Barke et al., 2009; Yakmaci-Guzel, 2013); In exothermic reactions, an increase in temperature will decrease the rate of the forward reaction (Banerjee, 1991; Sozbilir et al., 2010); Increasing temperature increases the rate of the reverse reaction since the equilibrium is shifted to the left (Banerjee, 1991; Yan & Subramaniam, 2016); In the CE condition the large vale of K causes the forward reaction to take place faster (Banerjee, 1991; Bilgin & Uzuntiryaki, 2003; Hackling & Garnett, 1985); The addition of reactants (solid phase) in a heterogeneous system causes a shift from the added side (Karpudewan et al., 2015; Piquette & Heikkinen, 2005; Sendur et al., 2011); The addition of a reactant at the gas equilibrium system will shift the equilibrium towards products (Karpudewan et al., 2015); Catalysts cause an increase in product concentration (Bilgin & Uzuntiryaki, 2003; Gorodetsky & Gussarsky, 1986; Hackling & Garnett, 1985; Voska & Heikkinen, 2000); Based on the results above, it shows that misconceptions occur in almost all concepts of CE.

Misconceptions of chemical concepts, including CE, are due to insufficient understanding of prior knowledge (Garnett et al., 1995). A misconception is a serious problem that may impact and hurdle the learning of subsequent concepts (Durmaz, 2018; Ilyas & Saeed, 2018; Papaphotis & Tsaparlis, 2008). For instance, misconceptions in one essential topic, such as atomic structure, can lead to misunderstandings in other related issues, such as chemical bonds (Erman, 2017).

Misconceptions are persistent and are difficult to change (Bodner, 1986; Nicoll, 2001). Therefore, its occurrence, especially in initial concepts, needs to be eliminated so that the subsequent concepts can be properly understood. Eliminations of misconceptions in several topics have been reported, such as Chemical Equilibrium (Canpolat et al., 2006; Atasoy et al., 2009), Equations of Chemical Reactions (Stojanovska et al., 2012), Properties of Matter, Atomic Structure, Chemical Reactions, and Stoichiometry (Regan et al., 2011), Acid-Base (Demircioglu et al., 2005), and Chemical Bonding (Eymur & Geban, 2017). Concepts that underlie the understanding of a concept in CE include reaction rate, concepts of moles and reaction equations, exothermic and endothermic reactions, and ideal gas equations. Even though these prerequisites concepts have been taught to students, they may still experience misconceptions before studying CE concepts.

Some researchers have reported misconceptions of prerequisite concepts in CE. Some of them are as follows; The number of molecules in the reaction composition is proportional to the subscript present in the structure (Sanger, 2005); The reaction rate remains from the beginning to the end; the rate of reaction increases with increasing reactant concentration (Kolomuç & Tekin, 2011); 'Catalyst does not affect the reaction; activation energy is the kinetic energy of the reactant molecule; catalyst increases the yield of the reaction; in endothermic reactions, the reaction rate increases with decreasing temperature' (Cakmacki, 2010); Exothermic reactions occur faster than endothermic reactions (Sozbilir et al., 2010); An increasing temperature of reaction causes a decrease in the reaction rate due to ineffective particle collisions (Driel, 2002); An increase in temperature caused an increase in the activation energy, and this leads to an increase in reaction rate (Habiddin &Page, 2019).

Some impacts of a prerequisite concepts misconception on an understanding of next related concepts are as follows; The misconception that "Temperature increases in an irreversible reaction system causes a decrease in reaction rate because ineffective particle collisions (Driel, 2002)" tends to affect students' understanding of the effects of temperature changes on a shift of chemical equilibrium; Misconception that "An increase in temperature can reduce the forward reaction and increase the reverse reaction rate (Hackling & Garnett, 1985)" tends to affect students' understanding of the value of the equilibrium constant; Misconception that "Reaction rate increases with decreasing concentrations of reactants (Kolomuç & Tekin, 2011)" tends to affect students' understanding of equilibrium state and dynamic equilibrium; Misconception that "Forward reaction will complete before the reverse reaction begins (Barke et al., 2009; Ozmen, 2008)" tends to affect students' understanding of reversible reaction. Misconceptions that "Number of moles of substances in the reaction equation proportional to the subscript of elements in compounds (Sanger, 2005)" tends to affect students' understanding of the effect of changes in pressure and volume on the gas equilibrium system; The same misconception was reported by Bilgin & Uzuntiryaki (2003) that the decrease in volume in the gas equilibrium system for the $2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ reaction would cause a greater concentration of NO and Cl_2 and a smaller NOCl concentration than the previous state. The misconception of the prerequisites concept has a significant impact on the misconception of the related ideas.

Based on the above studies, it is found that the nature of the concepts in chemistry is interconnected. Misconceptions occur in almost all chemical concepts, including reaction rates and chemical equilibrium. Misconceptions on the concept of prerequisites tend to be related to Chemical Equilibrium misconceptions. Thus, research on the impact of RR misconceptions on CE misconceptions is essential. This phenomenon is intended to show that misconceptions about RR have the potential to cause misunderstandings in CE. The research questions raised are: (1) Whether the misconceptions in RR have an impact on misconceptions in CE? (2) What is the correlation category between RR misconceptions and CE misconceptions?

Method

Research Design

This research applied a descriptive correlational design to identify RR misconceptions that have an impact on CE misconceptions. A correlational design is used to predict RR misconceptions that affect CE misconceptions (Cresswell, 2012, p 338). Descriptive analysis with semi-structured interviews was used to explain the causal relationship between RR and CE misconceptions.

Research Sample

This study was conducted on 245 eleventh grade students of Senior High School in Gowa, South Sulawesi, Indonesia, in the 2017/2018 academic year. The students were distributed in 8 homogeneous classes and have studied the RR and CE topics. Students sampled in this study were 16-18 years old, distributed to 189 females and 66 males.

Research Instruments and Procedure

Instruments used in this study include 1) three-tier misconception tests and 2) semi-structured interviews. The three-tier diagnostic test used to identify students' misconceptions in RR called RRDT consists of 15 items, while that of CE called CEDT consists of 30 items was develop by Jusniar et al. (2020). The misconception diagnostic instrument with certainty response index (CRI) has been used in biology subject by Miller & Romine (2020) and Arslan et al. (2012). Some items in the RRDT and CEDT were developed based on misconceptions reported in the previous study. Some others were developed based on learning outcomes set in the National Curriculum, namely the 2013 Revised Curriculum. RRDT was used to identify misconceptions about (a) state of the reaction rate, (b) rate of irreversible reaction, (c) effect of concentration, temperature, and catalyst on the rate of reaction, and (d) collision theory. These concepts are prerequisite to an understanding of concepts in CE. CEDT was used to identify misconceptions about (a) equilibrium condition, (b) dynamic equilibrium, (c) homogenous, heterogenous, and dissociation equilibrium, (d) effect of concentration, temperature, catalyst, pressure, volume, and addition of inert gas on an equilibrium system. Some examples of the test items RRDT and CEDT are given in the Appendix.

Before collecting data, RRDT and CEDT items tests were validated by three chemistry lectures and three chemistry teachers. Validators gave an average internal validity score of 90.7 for the RRDT and 96.7% for the CEDT. The reliability of the items test calculated using Cronbach alpha formula was 0.78 for the RRDT and 0.95 for CEDT. The empirical validity showed 15 items of RRDT are valid with (r) value ranging from 0.35 to 0.72, while that of 30 items of CEDT ranging from 0.37 to 0.81. RR test was carried out on March 26, 2018, while the CE test on March 30, 2018. Semi-structured interviews were given to 15 students who experienced misconceptions on RR concepts that impacted on CE misconceptions. Transcripts for each student are conducted for 30-60 minutes.

Data Analysis

Students who experience misconceptions were determined from the results of scoring by adapting criteria set by Arslan et al. (2012) and Hasan et al. (1999), as shown in Table 1. The distribution of student answers is based on patterns of answers, reasons, and level of confidence. The correct answer of the first-tier is given a score of 1, while an incorrect answer is given a score of 0. The second-tier is scored the same way. The level of student confidence in tier three consists of three levels of responses. The total score for the RRDT test is 30, while that of CEDT is 60.

Qualitative analysis is based on the answer patterns of students experiencing misconceptions according to the criteria in Table 1. The misconceptions are tabulated for each concept and calculated in percent for the material Reaction Rate and Chemical Equilibrium. Analyze student misunderstandings that occur in RR and CE topics according to the categories suggested by Al-Balushi et al. (2012) that a misunderstanding is considered a common misunderstanding if 20.0% or more of the sample believes in it. The next step is to identify students' misconceptions about RR that have a potential impact on misconceptions in CE. RR misconceptions that impact on CE misconceptions determine by a percentage of students who consistently experience both misunderstandings. This stage is supported by data obtained from semi-structured interviews conducted with 15 students who consistently experience misconceptions on RR and

CE. The number of students involved in the interview was in accordance with (Voska & Heikkinen, 2000). The results of the interview were transcribed and validated by two chemistry teachers.

Table 1. Criteria for Grouping Student Conceptions

First-tier	Second-tier	Third-tier	Category
True	True	Sure	Scientific knowledge
True	True	Unsure/guessing	Scientific knowledge
True	False	Unsure/guessing	Lack of knowledge
False	True	Unsure/guessing	Lack of knowledge
True	False	Unsure/guessing	Lack of knowledge
True	False	Sure	Misconception
False	True	Sure	Misconception
False	False	Sure	Misconception

The impact of misconception in RR on misconceptions in CE was expressed in Spearman's correlation coefficient. This analysis was chosen because the number of students' misconceptions data in RR and CE were not normally distributed (Creswell, 2012, p.339).

Before calculating the correlation coefficient, the normality test of the data was performed using the Kolmogorov-Smirnov Test (KS). The result of the analysis is given in Table 2.

Table 2. Result of Normality Test the Number of Students' Misconception (NSM) in RR and CE (N = 245)

Variable Tested	Test used	Criteria	Mean	KS_{Count}	KS_{Table}	Conclusion
NSM in RR	Kolmogorov-Smirnov Test (KS)	Normal Distribution If $KS_{count} < KS_{table}$	6.8	0.128	0.087	NSM in RR is not normally distributed
NSM in CE			9.8	0.106	0.087	NSM in CE is not normally distributed

Results

Descriptions of the conceptual understanding of students' of SMAN 2 Gowa on the RR and CE concepts are presented respectively in Tables 5 & 7 of the Appendix 2 section. Based on these data, it can be seen that of the 245 students distributed 24.5% have scientific knowledge, 45.7% have misconceptions, and 29.8% have less understanding of the RR concepts. While, the distribution of students' conceptual understanding of CE concepts is 25.3% scientific knowledge, 35.0% misconception, and 39.7% include a lack of knowledge. The pattern of students' misconception responses for each item on RRDT and CEDT is given in Tables 6 and 8 of Appendix 2. The misconceptions in RR having an impact on misconception in CE are given in Tables 3. The two variables tested were not normally distributed, so a nonparametric test was used, namely the Spearmans' RHO correlation. Correlation of misconception in RR and misconception in CE is given in Table 4.

Table 3. A Misconception in RR Having an Impact on the Misconception in CE (N = 245)

No	The misconception of Rate of Reaction	Ft/Fc	The Misconception of Chemical Equilibrium	F	%
1	The rate of reaction is the rate of increase in the number of reactants (item 1 RRDT; C2-III) and the rate of decrease in the number of products with time (item 1; A1-III).	54/32 58/29	Under equilibrium condition rate of increase in the amount of reactant is faster than the rate of decrease in the amount of product (item 3 CEDT; A4-III).	61	24.9
2	The rate of irreversible reaction is higher with time (item 4; A3-III).	60	Under the equilibrium condition rate of the forward reaction is faster than the rate of the reverse reaction (item 5; C1-III).	60	24.5
3	The rate of irreversible reaction is proportional to the subscript of an element in its formula (item 3; B4-III).	50	In gas equilibrium, increasing the system's volume shifts the equilibrium to an element having a higher index (item 26 A/B1-III).	50	20.4
4	The rate of reaction varies with time because the concentration of product and reactants vary with time (item 4; D3-III).	69/51	At dynamic equilibrium rates of forward and reverse reactions vary because amounts of reactants and products also vary(item 2; C3-III).	51	20.8

Table 3. Continued

No	The misconception of Rate of Reaction	Ft/Fc	The Misconception of Chemical Equilibrium	F	%
5	Catalyst accelerates the rate of reaction and increases the activation energy (item 9; B3-III).	118/57	Catalysts increase activation energy, so that forward reaction is faster than reverse reaction (item 22; A3-III)	57	23.3
6	Increasing temperature will increase activation energy (item 13; A1-III).	61	For exothermic reactions increasing temperature shifts equilibrium toward a product (item 21; B1,2-III)	61	24.9

Description: Ft: the frequency of students who have misconceptions about the answer choices.
Fc: The number of student responses that were consistent with related misconceptions.

Table 4. Results of Spearman's rho Analysis

Variable Tested	Test used	Range	Criteria	R	Sig.	Conclusion
NSM in RR- NSM in CE	Spearman's rho	> 0.85 0.66–0.85 0.35–0.65 0.35 <	Very good Good Moderate Slight	0.39	0.001	Correlation is significant, with the moderate category

Misconception number (1) and (2) in RR were experienced by 24.9 and 24.5% of students. Research results described above are supported by the result of the interview between Researchers (R) and students (S1) given below.

R: "What can you say about the rate of the following reaction

$CaCO_3(s) + HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$?"

S1: "I choose the reduced rate of $CaCl_2$ or CO_2 with time."

R: "Why?"

S1: "Because the rate is a reduction in product concentration every time unit."

R: "What do you think is the rate change for an irreversible reaction (item 4)?"

S1: "The reaction rate will be faster with increasing time."

R: "Why?"

S1: "Because the concentration of reactants will increase with increasing time."

R: "In item (3) of the CE What is the rate of the forward reaction compared to the rate of the reverse reaction in the equilibrium state?"

S1: "The reaction will continue with the forward reaction rate greater than the reverse reaction."

Misconception number (3) in RR that "Rate of irreversible reaction is proportional to the subscript of an element in its formula" was experienced by 20.4%. This misconception has an impact on misconception number (3) in CE that "In gas equilibrium increasing volume of the system shifts the equilibrium to an element having greater index." Research results described above are supported by the result of an interview between Researchers (R) and students (S5) given below.

R: "What is your answer for item 2 RRDT for the reaction."

$Na_2S_2O_3(aq) + 2HCl(g) \rightarrow 2NaCl(aq) + H_2O(l) + SO_2(g) + S(s)$

S5: "My answer is C-2. The rate of formation of sulfur dioxide is 1 mol/minute."

R: "What are your reasons?"

S5: "The number of moles is proportional to the coefficient and the number of subscripts an element in a compound."

R: "What is the rate of the reaction below

$2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$

S5: "I choose the speed of formation of oxygen gas equal ½ times nitrogen dioxide gas."

R: "What are your reasons?"

S5: "The number of nitrogen-oxygen atoms while nitrogen dioxide 4, so the rate formation of oxygen ½ times of nitrogen dioxide gas."

R: "For the reaction $H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)$ *at a fixed temperature, which the direction the equilibrium shift occurs when the volume is reduced?"*

S5: "Shift to the right."

R: "Why?"

S5: "The number of moles on the left "four" and the right "two," so that is equilibrium will shift to the right."

R: "How do you determine the number of moles of reactants and products?"

S5: "There are two moles of H and Br being a total of four and HBr is also two moles."

The student has an answer pattern B1-III item 26, identifying that "the decrease in volume in the gas equilibrium system will shift the equilibrium of $H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)$ towards the product".

Misconception number (4) in RR that "Rate of reaction varies with time because the concentration of product and reactants vary with time" was experienced by 20.8% of students. This misconception is due to misconceptions number (1) in RR. Misconception number (4) in RR having an impact on misconception number (4) in CE, i.e., "At dynamic equilibrium rates of forward and reverse reactions vary because amounts of reactants and products also vary." Research results described above are supported by the result of the interview between Researchers (R) and students (S2) given below.

R: "What do you think about rate of irreversible reaction?"

S2: "The reaction rate changes with time."

R: "Why?"

S2: "Because the concentration of reactant and product vary with time."

R: "How is the changing?"

S2: "No answer."

R: "What do you think about the rate of reversible reaction?"

S2: "In a reversible reaction the rate of the forward and reverse reaction is changed."

R: "Explains for reversible reaction, rate of the forward reaction decreases, then it becomes constant. The rate of reverse reaction increases, then it becomes constant. When the rate of the forward and reverse reactions is constant, an equilibrium is established. In the equilibrium, rate of forward and reverse reaction are the same."

R: "What is the type of this equilibrium?"

S2: "I choose dynamic equilibrium because of the number of substances changes and the rate of reaction also changes."

Misconception number (5) in RR that "Catalyst accelerates the rate of reaction and increases activation energy," was experienced by 23.3% of students. Misconception number (5) in RR has an impact on misconception number (5) in CE that "Catalysts increase activation energy so that forward reaction is faster than reverse reaction." Research results described above are supported by the result of the interview between Researchers (R) and students (S3) given below.

R: "What is the function of catalyst?"

S3: "Speed up the reaction."

R: "Why?"

S3: "Because the catalyst can increase activation energy."

R: "What is activation energy?"

S3: "The minimum energy required by reactant to do the reaction."

R: "What is the effect of a catalyst on the rate of forward and reverse reactions of a reversible reaction?"

S3: "The forward reaction rate is greater than the rate of the reverse reaction."

R: "Why?"

S3: "Because catalyst affects the rate of the forward reaction only."

Misconception number (6) in RR that "Increasing temperature will increase activation energy" was experienced by 24.9% of students. Misconception number (6) in RR has an impact of misconception number (6) in CE that "For an exothermic reaction, increasing temperature shifts equilibrium toward products." Research results described above are supported by the result of the interview between Researchers (R) and students (S4) given below.

R: "What do you think is the exothermic reaction?"

S4: "In my opinion reaction with positive enthalpy."

R: "What about endothermic reactions?"

S4: "The enthalpy price is negative."

R: "Which way the equilibrium shift occurs when the temperature is raised" for reaction

$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ *ΔH = - 905.6 kJ / mol?*

S4: "Shift to the right."

R: "Why?"

S4: "Increasing the temperature will increase the value of K, so the reaction shifts to the right."

R: "What will be the equilibrium shift with the decrease the temperature for the reaction

$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$ *ΔH = - 35 kJ?"*

S4: "I answer to the left."

R: "Why?"

S4: "A decrease in temperature will reduce the value of K, so the reaction will shift to the left."

R: "If a catalyst is added to the equilibrium system for the reaction below

$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ *ΔH = - 197,78 kJ.*

What is the ratio of the forward to the reverse reaction rate?"

S4: "I answer greater than one."

R: "Why?"

S4: "Because the catalyst will increase the activation energy."

Discussions

Misconception of the Rate of Reaction and Equilibrium Condition

Misconceptions about RR were revealed using the following reaction.

$CaCO_3(s) + HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

Proper understanding is that the reaction rate is the rate of reduction in the number of reactants or the rate of increase in the number of products with time (Burdge & Overby, 2017). Misconception number (1) can also be caused by students' lack of understanding of the rate of reaction's mathematical expression. As an example, reaction A → B has mathematical expressions as follows.

rate = $- \Delta[A])/\Delta t$

or

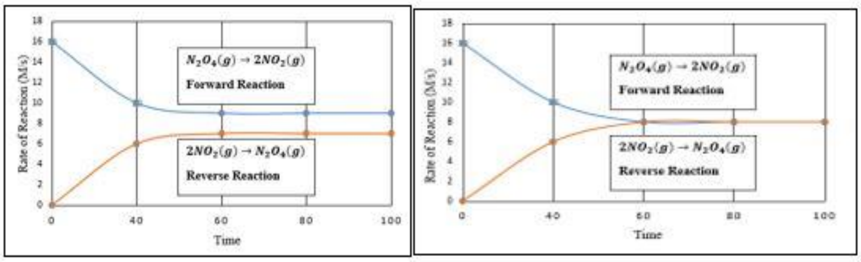
rate = Δ[B])/Δt

The negative sign indicates that the reaction concentration of the reactant decreases while the product's concentration increases (Burdge & Overby, 2017). Students who experience misconceptions (1) do not understand the physical meaning of those expressions. Misconceptions number (1) in RR has an impact on misconception number (1) in CE revealed using the following reaction.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

Misconception number (1) in CE was "Under equilibrium condition rate of increase in the amount of reactant is faster than the rate of decreasing in the amount of product," which is consistently experienced by 24.9% of students. This misconception was indicated by choice of answer (a) in Figure 1 by students. A misconception was the opposite of misconception reported in (Barke et al., 2009 and Voska & Heikkinen, 2000): "The rate of formation of product is faster than the rate of reactant formation." The correct equilibrium condition is shown by the answer, (b) in Figure 1. This figure indicates that the equilibrium condition is established after the reaction lasts for 40 units of time. The equilibrium condition rate of decomposition of N_2O_4 (forward reaction) is the same as the rate of formation of N_2O_4 (reverse reaction). Misconception number (1) in CE was an impact of misconception number (1) in RR because to understand equilibrium condition, an understanding of the rate of forward and reverse reactions is required.

Misconception number (2) in RR has an impact on misconception number (2) in CE that "Under equilibrium condition rate of the forward reaction is faster than the rate of reverse reaction," which is consistently experienced by 24.5% of students. Misconception (2) in CE is the opposite of misconception (1). This finding is parallel to that reported by Cakmakci (2010) in secondary school students in Turkey.



(a) (b)

Figure 1. Equilibrium State for Reaction N2O4(g) ⇌ 2NO2(g)

Misconception about the Relation of the Index of an Element in its Chemical Formula with the Rate of Reaction and Shift of an Equilibrium

Misconception number (3) in RR that "Rate of irreversible reaction is proportional to the subscript of an element in its formula." This misconception has an impact on misconception number (3) in CE that "In gas equilibrium increasing volume of the system shifts the equilibrium to an element having greater index," which is consistently experienced by 20.4%.

The correct understanding is that "Rate of irreversible reaction is proportional to the concentration of reactant." Further, based on the collision theory, "Rate of a reaction is directly proportional to the number of effective collisions per second between the reactant molecules." So, the reaction rate does not depend on the index of an element in its chemical formula.

Students who misconception assume that the number of reactants for reactions $H_2(g) + Br_2(g) \rightleftharpoons 2HBr(g)$ is four moles, and the number of products is two moles. This misconception is caused by students understanding the subscript of H and Br as the number of moles. This student understands that the number of moles on the left side is four moles, and on the right, there are two moles. These students are inconsistent in using coefficients with a subscript to express the number of moles of substances in the reaction equation. The correct concept is the number of moles on both sides of the same, so the change in gas pressure/volume will not shift the equilibrium position. The decrease in gas volume causes a shift in equilibrium in the direction of the small number of moles of gas (Burdge & Overby, 2017). Conversely, the increase in volume causes a shift towards a large number of moles of gas. For example, in the reaction of $N_2O_4(g) \rightleftharpoons 2NO_2(g)$, if the system volume is increased, it will shift to the right like Figure 2.

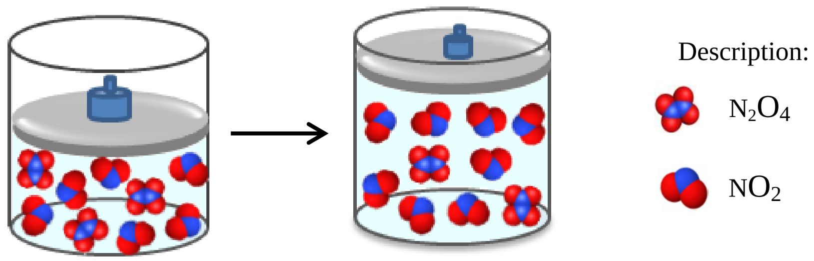


Figure 2. Equilibrium Shifts Due to Changes in Gas Volume

Based on the representation in Figure 2, it can be seen that before the gas volume is reduced, the number of NO_2 gas molecules is six, and N_2O_4 gas is three. After the gas volume increases, the number of gas molecules of N_2O_4 is two, and NO_2 gas is eight molecules. This picture indicates that the equilibrium shift towards the right (a small number of moles). Misconception about the number of moles of a substance in proportion to the number of subscripts of its elements is caused by students' lack of understanding in distinguishing between reaction coefficients and element subscripts. The same phenomenon has been reported by Nakhleh (1992) that students misinterpret chemical reaction equations due to a lack of understanding to distinguish reaction coefficients and the index of an element.

Misconception about Changing Concentration of Substances During the Reaction

Misconception number (4) due to misconceptions number (1) in RR. Misconception number (4) in RR having an impact on misconception number (4) in CE, i.e., "At dynamic equilibrium rates of forward and reverse reactions vary because amounts of reactants and products also vary," which is consistently experienced by 20.8% of students. Misconception number (4) in RR shows that students do not understand that an irreversible reaction concentration or amount of reactant decreases. In contrast, concentration or amount of product increases with increasing reaction time. Because of this, students do not understand that at equilibrium concentration or amount of substances remains constant.

Students' conceptions of changing in concentration or amount of substances at dynamic equilibrium might relate to the notion of the word "dynamic," which means changing. However, students who experience misconceptions do not understand how these changes occur. So far, misconceptions about changing in concentration or amount of substances at dynamic equilibrium have never been reported. The findings of dynamic and static equilibrium misconceptions have been reported by Gussarsky & Gorodetsky (1990).

Misconceptions about Catalyst and Rate of Reaction

Misconception number (5) in RR that "Catalyst accelerates the rate of reaction and increases activation energy" indicates that students do not have a correct understanding of catalysts. The correct understanding is that catalyst speeds up a reaction by lowering the activation energy, such as illustrated in Figure 3 for the following reaction.

$A + B \rightarrow C + D$

Figure 3 also indicates that the catalyst reduces energy barriers but does not affect the potential energy of reactant and product, as mentioned in Burdge and Overby (2017).

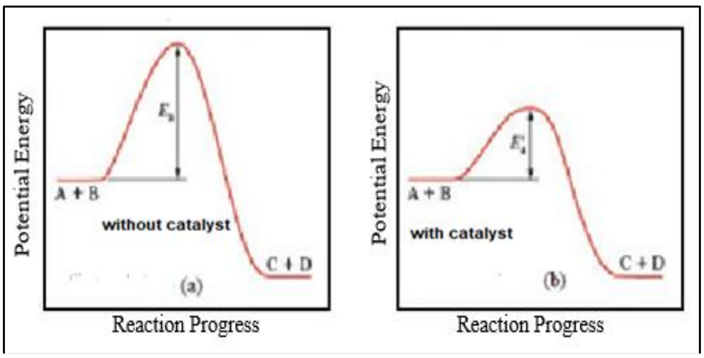


Figure 3. Activation Energy (a) Without Catalysts and (b) With Catalysts

Misconception number (5) in RR has an impact on misconception number (5) in CE that "Catalysts increase activation energy so that forward reaction is faster than reverse reaction." This misconception, which is consistently was experienced by 23.3% of students and indicated that students do not understand that catalyst decreases the activation energy of both forward and reverse reactions, not just the forward reaction. This misconception is similar to that reported for first-degree students of science education study program in Turkey (Ozmen, 2008), in Middle School students in Malaysia (Karpudewan et al., 2015), and Izmir Turkish Middle School (Sendur et al., 2011).

Misconceptions Temperature, Activation Energy, and Shift of Equilibrium

Misconception number (6) in RR: "Increasing temperature will increase activation energy". As a consequence of this misconception, the reaction rate will decrease with increasing temperature. The correct understanding is that increasing temperature does not change the value of activation energy. Increasing temperature caused increases the kinetic energy of reactants, the number of a collision, including effective collision, and reaction becomes faster. For a reversible reaction, the increasing temperature does not change the value of activation energy of the forward and reverse reactions (Burdge & Overby, 2017). Misconception number (6) in RR has an impact of misconception number (6) in CE that "For an exothermic reaction, increasing temperature shifts equilibrium toward products," which is consistently experienced by 24.9% of students. This misconception implies that students may not understand what exothermic reaction. Students may perceive that exothermic reaction is one having a positive value of enthalpy change, $\Delta H > 0$.

The Impact of Misconception in RR on Misconceptions in CE

As mentioned above, misconceptions in RR impacting on the misconception in CE have a correlation coefficient of 0.39. This value indicates that the effect is moderate (Creswell, 2012). A similar study has been reported by Yurdakal (2019) by correlating attitude toward reading with creative perception reading.

Conclusion

This study revealed misconceptions in the RR and CE. Some of the misconception in RR has an impact on misconception in CE. Misconception that "RR is rate of increase in the number of reactants and decrease in the number of products with time" has an impact on the misconception that "Under equilibrium condition rate of increase in the amount of reactant is faster than the rate of decreasing in the amount of product." The misconception that "Rate of irreversible reaction is higher with time" has an impact on a misconception that "Under equilibrium condition rate of the forward reaction is faster than the rate of reverse reaction." The misconception that "RR is proportional to the index of an element in its formula," has an impact on a misconception that "Shifting of equilibrium is directed to an element having greater index." The misconception that "RR varies with time because the concentration of product and reactants vary with time" has an impact on a misconception that "At dynamic equilibrium rates of forward and reverse reactions vary because amounts of reactants and products also vary." A Misconception that “Catalyst accelerates the rate of reaction and increases activation energy," impacts the misconception that "Catalysts increase activation energy so that forward reaction is faster than reverse reaction." The Misconception that "Increasing temperature will increase activation energy" in RR has an impact on the misconception in CE that "For exothermic reaction increasing temperature shifts equilibrium toward product." The impact of misconceptions in RR on misconceptions in CE can be categorized as moderate.

Recommendation

The existence of several misconceptions on the concept of RR that impact on CE misconceptions, the teacher needs to eliminate students' prerequisites of misconceptions before teaching Chemical Equilibrium. In general, chemical concepts' characteristics are interconnected, so it is essential to explore students' prerequisite concepts before learning new related concepts. The next researcher can involve several schools with different characteristics to explore misconceptions relate to concepts. Researchers can further enrich the literature by correlating students' misconceptions with other variables such as scientific reasoning ability.

Limitation

This research was only conducted at one school involving a large sample and was focused only on related misconceptions. Other variables that caused misconceptions are not examined, such as teachers, textbooks, languages, and other sources of information accessed by students. The next researchers can supplement this limitation.

References

Al-Balushi, S. M., Ambusaidi, A. K., Al-Shuaili, A. H., & Taylor, N. (2012). Omani twelfth grade students’ most common misconceptions in chemistry. *Science Education International*, *23*(3), 221–240. https://doi.org/10.1016/j.sbspro.2015.04.478.

Ambrose, S. A., Bridges, M. W., & Dipietro, M. (2010.). *How learning works. Seven research-based principles for smart teaching*. Jossey Bass Willey Imprint.

Arslan, H. O., Cigdemoglu, C., & Moseley, C. (2012). A three-tier diagnostic test to assess pre-service teachers’ misconceptions about global warming, greenhouse effect, ozone layer depletion, and acid rain. *International Journal of Science Education*, *34*(11), 1667–1686. https://doi.org/10.1080/09500693.2012.680618.

Atasoy, B., Akkus, H., & Kadayifci, H. (2009). The effect of the conceptual change approach on an understanding of student chemical equilibrium concept. *Research in Science and Technology Education, 27*(3), 267-282. doi.org/10.1080/02635140903162587.

Banerjee, A. C. (1991). Misconceptions of students and teachers in chemical equilibrium. *International Journal of Science Education*, *13*(4), 487–494. https://doi.org/10.1080/0950069910130411

Barke, H. -D., Hazari, A., & Yitbarek, D. (2009). Chemical Equilibrium. In *Misconceptions in Chemistry* (pp. 145-172). Springer. https://doi.org/10.1007/978-3-540-70989-3_7

Bilgin, I., & Uzuntiryaki, E. (2003). Student's misconceptions on the concept of chemical equilibrium. *Education and Science*, *28*(127), 10–17.

Bodner, G.M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education*, *63*, 873-878. https://doi.org/10.1021/ed063p873

Burdge, J., & Overby, J. (2017). *Chemistry atom* (3rd ed.). McGraw Hill.

Cakmakci, G. (2010). Identifying alternative conceptions of chemical kinetics among secondary school and undergraduate students in Turkey. *Journal of Chemical Education*, *87*(4), 449–455. https://doi.org/10.1021/ed8001336

Canpolat, N., Pinarbasi, T., Bayracheken, S., & Geban, O. (2006). The conceptual change approach to teaching chemical equilibrium. *Journal of Research Science Teaching Education, 24*(2), 217-235. https://doi.org/10.1080/02635140600811619.

Carey, S. (2000). Science education as conceptual change. *Journal of Applied Development Psychology, 21*(1), 13-19. https://doi.org/10.1016/s0193-3973(99)00046-5

Cook, M, Wiebe, E.N., & Carter, G. (2008). The influence of prior knowledge on viewing and interpreting graphics with macroscopic molecular representations. *Science Education, 92*, 848-867. https://doi.org/10.1002/sce.20262

Creswell, J.W. (2012). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research.* Pearson.

Demircioglu, G., Ayas, A., & Demircioglu, H. (2005). Conceptual change is achieved through a new teaching program on acids and bases. *Chemistry Education Research and Practice*, *6*(1), 36–51. https://doi.org/10.1039/b4rp90003k

Dhindsa, H. S., & Treagust, D. F. (2014). Prospective pedagogy for teaching chemical bonding for smart and sustainable learning. *Chemistry Education Research and Practice*, *15*(4), 435–446. https://doi.org/10.1039/c4rp00059e.

Driel, J.H. Van. (2002). Students' corpuscular conceptions in the context of chemical equilibrium and chemical kinetics. *Chemistry Education Research Practice Europa, 3*(2), 201-213. https://doi.org/10.1039/b2rp90016e

Durmaz, M. (2018). Determination of prospective chemistry teachers' cognitive structures and misconceptions about stereochemistry. *Journal of Education and Training Studies*, *6*(9), 13-20. https://doi.org/10.11114/jets.v6i9.3353

Effendy. (2002). Upaya untuk mengatasi kesalahan konsep dalam pengajaran kimia dengan menggunakan strategi konflik kognitif [Efforts to overcome misconceptions in chemistry teaching by using cognitive conflict strategies]. *Chemical Communication Media/ Media Komunikasi Kimia*, *6*(2), 1-22.

Erman, E. (2017). Factors contributing to students' misconceptions in learning covalent bonds. *Journal of Research in Science Teaching*, *54*(4), 520–537. https://doi.org/10.1002/tea.21375

Eymur, G., & Geban, O. (2017). The collaboration of cooperative learning and conceptual change: Enhancing the students' understanding of chemical bonding concepts. *International Journal of Science and Mathematics Education*, *15*(5), 853–871. https://doi.org/10.1007/s10763-016-9716-z

Ganasen, S., & Shamuganathan, S. (2017). The Effectiveness of Physics Education Technology (PhET) Interactive Simulations in Enhancing Matriculation Students' Understanding of Chemical Equilibrium and Remediating Their Misconceptions. In M. Karpudewan, A. Md Zain & A. Chandrasegaran (Eds.), *Overcoming Students' Misconceptions in Science* (pp. 157-175). Springer. https://doi.org/10.1007/978-981-10-3437-4_9

Garnett, P. J., Garnett, P. J., & Hackling, M. W. (1995). Student alternative conception in chemistry: A review of research and implications for teaching and learning. *Studies in Science Education, 25*, 69-95. https://doi.org/10.1080/03057269508560050.

Gorodetsky, M., & Gussarsky, E. (1986). Misconceptualization of the chemical equilibrium concept as revealed by different evaluation methods. *European Journal of Science Education, 8*(4), 427-441. https://doi.org/10.1080/0140528860080409.

Gussarsky, E., & Gorodetsky, M. (1990). On the concept of "chemical equilibrium": The associative framework. *Journal of Research in Science Teaching*, *27*(3), 197–204. https://doi.org/10.1002/tea.3660270303

Habiddin & Page, E. M. (2019). Development and validation of a four-tier diagnostic instrument for chemical kinetics (FTDICK). *Indonesia Journal of Chemistry, 19*(3), 720–736. https://doi.org/10.22146/ijc.39218.

Hackling, M. W., & Garnett, P. J. (1985). Misconceptions of chemical equilibrium. *European Journal of Science Education*, *7*(2), 205–214. https://doi.org/10.1080/0140528850070211

Hasan, S., Bagayoko, D., & Kelley, E. L. (1999). Misconceptions and the certainty of the response index (CRI). *Physics Education*, *34*(5), 294–299. https://doi.org/10.1088/0031-9120/34/5/304

Horton, C. (2007). Students' alternative conception in chemistry. *California Journal of Science Education, 7*(2), 18-38.

Ilyas, A., & Saeed, M. (2018). Exploring teachers ' understanding of misconceptions of secondary grade chemistry students. *International Journal for Cross-Disciplinary Subject in Education, 9*(1), 3323–3328.

Johnstone, A.H. (2000). The teaching of chemistry logical or psychological. *Chemistry Education Research and Practice, 7*(2), 49-63. https://doi.org/10.1039/a9rp90001b

Jusniar, J., Effendy, E., Budiasih, E., & Sutrisno, S. (2020). Developing a three-tier diagnostic instrument on chemical equilibrium (TT-DICE). *Educacion Quimica*, *31*(3), 84–102. https://doi.org/10.22201/fq.18708404e.2020.3.72133

Karpudewan, M., Treagust, D. F., Mocerino, M., Won, M., & Chandrasegaran, A. L. (2015). Investigating high school students' understanding of chemical equilibrium concepts. *International Journal of Environmental and Science Education*, *10*(6), 845–863. https://doi.org/10.12973/ijese.2015.280a

Kolomuç, A., & Tekin, S. (2011). Chemistry teachers' misconceptions concerning the concept of chemical reaction rate. *Eurasian Journal of Physics and Chemistry Education*, *3*(2), 84-101.

Nakhleh, M. (1992). Why some students don't learn chemistry chemical misconceptions. *Journal of Chemical Education, 69*(3), 191–196. https://doi.org/10.1021/ed069p191.

Nicoll, G. (2001). A report of undergraduates' bonding misconceptions. *International Journal of Science Education*, *23*(7), 707–730. https://doi.org/10.1080/09500690010025012.

Miller, M., & Romine, W. (2020). Assessing college students' knowledge and misconceptions concerning the Ebola virus. *European Journal of Educational Research, 9*(2), 579 - 602.

O'Connor, C. (2015). A practice-led approach to aligning learning theories with learning and teaching strategies in third level chemistry education. *Irish Journal of Academic Practice*, *4*(1), 1-17. https://doi.org/10.21427/D7B42F

Osborne, R. J., & Wittrock, M. C. (1983). Learning science : A generative process. *Science Education, 67*(4), 489–508. https://doi.org/10.1002/sce.3730670406.

Ozmen, H. (2008). Determination of students' alternative conceptions about chemical equilibrium: A review of research and the case of Turkey. *Chemistry Education Research and Practice*, *9*(3), 225–233. https://doi.org/10.1039/B812411F

Papaphotis, G., & Tsaparlis, G. (2008). Conceptual versus algorithmic learning in high school chemistry: The case of basic quantum chemical concepts Part 2. Students' common errors, misconceptions, and difficulties in understanding. *Chemistry Education Research and Practice*, *9*(4), 332–340. https://doi.org/10.1039/b818470b.

Piquette, J. S., & Heikkinen, H. W. (2005). Strategies reported used by instructors to address alternate student conceptions in chemical equilibrium. *Journal of Research in Science Teaching*, *42*(10), 1112–1134. https://doi.org/10.1002/tea.20091

Regan, A., Childs, P., & Hayes, S. (2011). The use of an intervention program to improve undergraduate students' chemical knowledge and address their misconceptions. *Chemistry Education Research and Practice*, *12*(2), 219–227. https://doi.org/10.1039/c1rp90027g

Sanger, M. J. (2005). Evaluating students' conceptual understanding of balanced equations and stoichiometric ratios using a particulate drawing. *Journal of Chemical Education*, *82*(1), 131–134. https://doi.org/10.1021/ed082p131.

Seery, M. K. (2009). The role of prior knowledge and student aptitude in undergraduate performance in chemistry: A correlation-prediction study. *Chemistry Education Research and Practice*, *10*(3), 227–232. https://doi.org/10.1039/b914502h.

Sendur, G., Toprak, M., & Pekmez, E.S. (2011) How can secondary school perceive chemical equilibrium. *New World Science Academic, 6*(2), 1512-1531.

Shing, Y. L., & Brod, G. (2016). Effects of prior knowledge on memory: Implications for education. *International Mind, Brain, and Educational Society, 10*(3), 1-9. https://doi.org/10.1111/mbe.12110

Sozbilir, M., Pinarbasi, T., & Canpolat. (2010). Prospective chemistry teachers' conceptions of chemical. *Eurasia Journal of Mathematics, Science, and Technology Education*, *6*(2), 111-120. https://doi.org/10.12973/ejmste/75232.

Stojanovska, M. I., Petrusevski, V. M., & Soptrajanov, B. T. (2012). Addressing students' misconceptions concerning chemical reactions and symbolic representations. *Chemistry Bulgarian Journal of Science Education*, *21*(6), 829–852.

Stojanovska, M. I., Petrusevski, V. M., & Soptrajanov, B.T. (2017). Study of the use of the three levels of thinking and representation contributions. *Section of Natural, Mathematical and Biotechnical Sciences*, *35*(1), 37–46. https://doi.org/10.20903/csnmbs.masa.2014.35.1.52.

Taber, K.S. (2009). Challenging misconceptions in the chemistry classroom: Resources to support teachers. *Education Quimica*, *4,* 13–20. https://doi.org/102436/20.2003.02.27.

Talanquer, V. (2011). Macro, submicro, and symbolic: The many faces of the chemistry "triplet." *International Journal of Science Education*, *33*(2), 179–195. https://doi.org/10.1080/09500690903386435.

Tyson, L., Treagust, D. F., & Bucat, R. B. (1999). The complexity of teaching and learning of chemical equilibrium. *Journal of Chemical Education*, *76*(4), 554-558. https://doi.org/10.1021/ed076p554.

Voska, K. W., & Heikkinen, H. W. (2000). Identification and analysis of student conceptions used to solve chemical equilibrium problems. *Journal of Research in Science Teaching*, *37*(2), 160–176. https://doi.org/10.1002/(SICI)1098-2736

Yakmaci-Guzel, B. (2013). Preservice chemistry teachers in action: An evaluation of attempts for changing high school students' chemistry misconceptions into more scientific conceptions. *Chemistry Education Research and Practice*, *14*(1), 95–104. https://doi.org/10.1039/c2rp20109g

Yan, Y. K., & Subramaniam, R. (2016). Diagnostic appraisal of grade 12 students' understanding of reaction kinetics. *Chemistry Education Research and Practice*, *17*(4), 1114-1126. https://doi.org/10.1039/c6rp00168h

Yurdakal, I. H. (2019). Examination of correlation between attitude towards reading and perception of creative reading. *European Journal of Educational Research, 8*(2), 443 - 452.

Appendix 1. Specimen items on RRDT

1. Rection: $CaCO_3(s)$ + $HCl(aq)$ → $CaCl_2(aq)$ + $H_2O(l)$ + $CO_2(g)$.

   The reaction rate above can be stated by .... (Item 1 in RRDT)

   (A) reduced in the amount of $CaCl_2$ or amount of CO_2 unity of time.

   (B) increase in the amount of $CaCl_2$ or CO_2 unity of time.

   (C) increase in the amount of $CaCl_2$ or HCl unity of time

   (D) increase in the amount of HCl, $CaCl_2$, and CO_2 unity of time.

Reason:

1) The rate of reaction is a reduction in the concentration of product unity of time.
2) The reaction rate is the addition of the reactant concentration unity of time.
3) The rate of reaction is the addition of the product concentration unity of time.
4) The rate of reaction is the reduction of the reactant concentration unity of time.

Confidence Level:

I. Guess; II. Not sure; III. Sure

2. At a temperature of 25 ^oC a reaction occurs as follows: (Item 2 in RRDT)

   $Na_2S_2O_3(aq) + 2HCl(g) \rightarrow 2NaCl(aq) + H_2O(l) + SO_2(g) + S(s)$

   If the rate of formation of sulfur is 2 mol/minute, then ...

   (A) the rate of reduction of sodium thiosulfate is 1 mol/ minute

   (B) the rate of formation of sodium chloride is 4 mol/minute

   (C) the gas formation rate of sulfur dioxide is 1 mol/minute

   (D) the rate of formation of sodium chloride is 2 mol/minute

Reason:

1) The reaction rate is directly proportional to the reaction coefficient, so the rate of removal of $Na_2S_2O_3$ is twice the rate of formation of sulfur deposits.
2) The reaction rate is directly proportional to the reaction coefficient, so the rate of NaCl formation is twice the rate of formation of sulfur deposits.
3) The reaction rate is inversely proportional to the reaction coefficient so that the rate of formation of SO_2 gas is twice the rate of formation of sulfur deposits.
4) The reaction rate is inversely proportional to the reaction coefficient, so the rate of formation of NaCl is twice the rate of formation of sulfur deposits.

Confidence Level:

I. Guess; II. Not sure; III. Sure.

3. Catalysts for chemical reactions can .... (Item 9 in RRDT)

   (A) slows down the reaction

   (B) speed up the reaction

   (C) decreases the number of products formed

   (D) increase the number of products formed

Reason:

1) The catalysts increase the potential energy of the reactants.
2) The catalyst lowers the activation energy of the reaction.
3) The catalyst increases the activation energy of the reaction

4) the catalysts reduce the potential energy of the reactants.

Confidence Level:

I. Guess; II. Not sure; III. Sure.

4. The minimum energy needed by the reactants for the reaction is called ....(Item 10 in RRDT)

(A) potential reaction energy

(B) activation energy

(C) impact energy

(D) transition energy

Reason:

1) Reactants must have a certain amount of energy for collisions.

2) Reactants must have activation energy for effective collisions.

3) Reactants must have a minimum amount of energy needed for chemical reactions to occur.

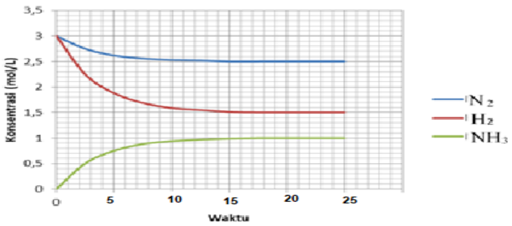
4) Reactants must have activation energy for chemical reactions to occur.

Confidence Level:

I. Guess; II. Not sure; III. Sure.

Specimen items on CEDT

1. The relationship between the partial pressure of the substances and the reaction time at 450 oC as below. (Item 1 in CEDT)



The graph shows a reaction ...

(A) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ and equilibrium occur after 20 units of time

(B) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ and equilibrium occur after 15 units of time

(C) $2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g)$ and equilibrium occur after 20 units of time

(D) $2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g)$ and equilibrium occur after 15 units of time

Reason:

1) The partial pressure of substances after 15 units of time is the same.

2) The partial pressure of substances after 15 units of time is fixed.

3) The partial pressure of substances after 20 units of time is the same.

4) The partial pressure of substances after 20 units of time is fixed.

Confidence Level:

I. Guess; II. Not sure; III. Sure

2. The system or reaction state, as found in the graph of question no. 1 is .... (Item 2 in CEDT)

(A) physical equilibrium

(B) static equilibrium

(C) dynamic equilibrium

(D) relative equilibrium

Reason:

1) The number of the same substances and the rate of product formation and the re-formation of the reactants are at the same speed.
2) The number of different substances and the rate of product formation faster than the re-formation of reactants.
3) The number of substances changes, and the rate of product formation and the formation of reactants change constantly.
4) The number of fixed substances, as well as the rate of product formation and decomposition, takes place at the same speed.

Confidence Level:

I..Guess; II. Not sure; III. Sure

3. At 250 °C Calcium carbonate decomposes to form calcium oxide and carbon dioxide according to the equation: $CaCO_3(s)$ + heat $\rightleftarrows$ $CaO(s) + CO_2(g)$.

After the system reaches equilibrium in a closed container, $CaCO_3$ is added to the equilibrium mixture. What will happen if $CaCO_3$ Solid is taken part of the system? (Item 20 in CEDT)

(A) shift to the reactants' side

(B) will not shift the equilibrium

(C) unpredictable

(D) shift to the product side

Reason:

1) The amount of $CaCO_3$ increases in the system; a new equilibrium will occur.
2) Because $CaCO_3$ has a solid-state, it does not affect K.
3) CO_2 and CaO react to form $CaCO_3$, according to the Le-Chatelier Principle.
4) The amount of solid $CaCO_3$ decreases in the system so that it will shift towards the reactants

Confidence Level:

I. Guess; II. Not sure; III. Sure

4. The reaction between ammonia and oxygen gases forms nitrogen monoxide and water vapor such as: $4NH_3(g) + 5O_2(g) \rightleftarrows 4NO(g) + 6H_2O(g)$ $\Delta H = -905.6$ kJ / mol.

If the system temperature is raised, the equilibrium will shift towards ... (Item 21 in CEDT; Modify from Ozmen, 2008)

(A) Left

(B) Right

(C) Constant

(D) unpredictable

Reason:

1) An increase in temperature always increases the numerical value of K_p.
2) The reaction is exothermic so that the concentration of the product increases.
3) An increase in temperature causes decreases in the value of K_p.
4) Endothermic or exothermic reactions do not affect the value of Kp.

Confidence Level:

I. Guess; II. Not sure; III. Sure

5. At certain temperatures, sulfur dioxide and oxygen gas react to form sulfur trioxide. Equilibrium occurs according to the reaction: (Item 23 in CEDT; Modify from Hackling & Garnett, 1985; Ozmen, 2008)

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)\ \Delta H = -\ 197{,}78\ kJ.$$

If a catalyst is added to the equilibrium system, then the ratio of the forward reaction rate to the reverse reaction rate will ...

(A) greater 1 (> 1)

(B) smaller (<1)

(C) equal (= 1)

(D) equals 0 (= 0)

Reason:

1) Catalysts can increase collisions between reactant molecules and produce more products.

2) Catalysts reduce the activation energy to form the product and react again at the same rate.

3) Catalysts increase activation energy so that the reaction rate progresses faster than the reverse reaction.

4) Catalysts do not affect activation energy, so fewer products are formed.

Confidence Level:

I. Guess; II. Not sure; III. Sure

Appendix 2.

Table 5. Distribution of Student's Understanding of Reaction Rate Concepts

Concept/ Item		Rate of reaction					Effect of concentration			Effect of catalyst				Effect of temperature			% Avarage
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Scientific knowledge	F	25	31	54	23	25	51	121	52	40	20	165	52	72	23	142	24.5
	%	10.2	12.7	22	9.39	10.2	20.8	49.4	21.2	16.3	8.2	67.3	21.2	29.4	9.39	58	
Miscon-ception	F	124	62	119	148	99	109	76	126	152	160	62	123	113	140	68	45.7
	%	50.6	25.3	48.6	60.4	40.4	44.5	31	51.4	62	65.3	25.3	50.2	46.1	57.1	27.8	
Lack of knowledge	F	96	152	72	74	119	85	48	67	53	65	18	70	60	82	35	29.8
	%	39.2	62	29	30.2	48.6	34.7	20	27	21.6	26.5	7.4	28.6	24.5	33	14	
Total		245	245	245	245	245	245	245	245	245	245	245	245	245	245	245	100

Table 6. The Pattern of Student Responses to the Reaction Rate Misconceptions

Concept/ Item	Rate of reaction					Effect of concentration			Effect of catalyst				Effect of temperature		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
The number of students' misconceptions (NSM)	124	62	119	148	99	109	76	126	152	160	62	123	113	140	68
Answer pattern (Frequency)	A1 (54)	A1 (34)	A2 (57)	C2 (19)	C2 (51)	B1 (54)	B1 (45)	A/B1 (49)	B1 (19)	B3 (98)	C2 (15)	C1 16 A1 (89)	A/C1 (59)	A1 (78) C-1 19	B1 (15)
Answer pattern (Frequency)	C2 (58)	D2 (13)	C3 12	A3 (60)	B1 (8) B3 (34)	C2 (42)	C3 (20)	A3 (20)	B3 (118)	C1 (37)	B/C3 (30)	D3 (3)	A/D3 (20)	C2 (11)	A3 (34)
Answer pattern (Frequency)	D4 (12)	C3/4 (15)	B4 (50)	D4 (69)	B4 (6)	D4 (13)	A4 (11)	A4 (57)	D4 (15)	B/C2 (25)	C4 (17)	D2 (15)	B4 (34)	A4 (32)	C4 (19)

Table 7. Distribution of Student's Understanding of Chemical Equilibrium Concepts

Concept/ Item		Equilibrium state & dynamic equilibrium						Homogeneous, heterogeneous, & dissociation equilibrium				*K_p and K_c*				
		1	2	3	4	5	6	7	8	9	10	11	12	13	15	16
Scientific knowledge	F	82	33	63	60	38	115	93	132	170	65	37	59	31	36	70
	%	33.5	13.5	25.7	24.5	15.5	46.9	37.96	53.88	69.4	26.5	15.1	24.08	12.7	14.7	28.6
Misconcep-tion	F	93	118	99	116	98	58	33	36	20	87	119	117	109	79	107
	%	38.0	48.2	40.4	47.3	40	23.7	13.47	14.69	8.16	35.5	48.57	47.76	44.5	32.2	43.7
Lack of knowledge	F	70	94	83	69	109	72	119	77	55	93	89	69	105	130	68
	%	28.6	38.4	33.9	28	44.5	29.4	48.6	31.4	22.4	38	36.3	28.2	43	53.1	27.8
Total		245	245	245	245	245	245	245	245	245	245	245	245	245	245	245

Table 7. Continued

Concept/ Item		*K in heterogeneous equilibrium*		The shift in equilibrium due to changes in concentration, volume, temperature, and catalyst											Chemical equilibrium application		% Avara-ge
		14	**20**	**17**	**18**	**19**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	
Scientific knowledge	**F**	**80**	**48**	**10**	**64**	**42**	**83**	**50**	**75**	**23**	**17**	**27**	**28**	**19**	**83**	**129**	
	%	**32.7**	**19.6**	**4.1**	**26.1**	**17.1**	**33.9**	**20.4**	**30.6**	**9.4**	**6.9**	**11.0**	**11.4**	**7.8**	**33.9**	**52.6**	25.3
Misconception	**F**	**125**	**77**	**102**	**73**	**105**	**77**	**96**	**71**	**90**	**84**	**89**	**77**	**78**	**68**	**73**	
	%	**51**	**31.4**	**41.6**	**29.8**	**42.9**	**31.4**	**39.2**	**29**	**37**	**34.3**	**36.3**	**31.4**	**31.8**	**27.7**	**29.8**	35.0
Lack of knowledge	**F**	40	120	133	108	98	85	99	99	132	144	129	140	148	94	43	
	%	16.3	49	54.3	44.1	40	34.7	40.4	40.4	54	59	52.7	57.2	60.2	38.4	17.6	39.7
Total		**245**	**245**	**245**	**245**	**245**	**245**	**245**	**245**	**245**	**245**	**245**	**245**	**245**	**245**	**245**	**100**

Table 8. The Pattern of Student Responses to the Chemical Equilibrium Misconceptions

Concept/ Item	Equilibrium state & dynamic equilibrium						Homogeneous, heterogeneous, & dissociation equilibrium				*K_p and K_c*				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**15**	**16**
The number of students' misconceptions (NSM)	93	118	99	116	98	58	33	36	20	88	119	117	109	79	107
Answer pattern (Frequency)	B1 (41)	B1 (42)	C1 (11)	A1 (21)	C1 (67)	B1 (20)	A1 (16)	B2 (7)	B1-3	C1 (21)	C2 (13)	D1 (49)	A1 (47)	B1 (39) D1 (16)	A2 (17)
Answer pattern (Frequency)	C3 (34)	D2 (25)	D2 (27)	B2 (10)	B4 (20)	A3 (31)	C3 (9)	A3 (16)	A3 (14)	A2 (18)	C3 (35)	D2 (26) A3 (20)	B2 (43)	D2 (10)	A3 (35)
Answer pattern (Frequency)	A4 (18)	C3 (51)	A4 (61)	C3 (57) C4 (18)	D4 (11)	C1 (7)	D4 (8)	C/D4 (13)	A4 (2)	B4 (49)	B4 (71)	B4 (22)	D1 (19)	C4 (14)	B4 (55)

Table 8. continued

Concept/ Item	*K in heterogeneous equilibrium*		The shift in equilibrium due to changes in concentration, volume, temperature, and catalyst											Chemical equilibrium application	
	14	**20**	**17**	**18**	**19**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
The number of students' misconceptions (NSM)	125	77	102	73	105	77	96	71	90	84	89	77	78	68	73
Answer pattern (Frequency)	C1 (20)	D2 (4)	C1 (61)	C1 (15)	A1 (36)	B1 (37)	B2 (21)	A/C1 (11)	A1 (29) C1 (31)	A/B1 (35)	A/B1 (79)	B2 (20)	A/B1 (15)	B1 (33)	A/C1 (38)
Answer pattern (Frequency)	A2 (73)	A3 (17)	A2 (10) B2(20	B3 (28)	B3 (54)	B2 (24)	A3 (67)	A3 (57)	A2 (11)	A2 (37)	B2 (7)	C/D3 (45)	A2 (31)	A/D2 (13)	B2-8 C3-9