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STUDENTS' CONCEPTUAL UNDERSTANDING IN CHEMISTRY LEARNING USING PHET INTERACTIVE SIMULATIONS

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Abstract

This research aims to analyse students' conceptual understanding of chemical equilibrium matter using Physics Education Technology (PhET) Interactive Simulations. Students' misconceptions can be caused by the difficulty in connecting the sub-microscopic, macroscopic, and symbolic levels of understanding in chemistry. The study was conducted at a secondary school with a total sample of 108 students using a quantitative research method. The results showed that multiple-choice questions of the two-tier Chemical Equilibrium Diagnostic Instrument (CEDI) used in this study meet with the Rasch measurement model. The students who answered correctly on content knowledge ranged from 11.1-90.7%. However, the percentage decreased to 11.1-84.3% once the content knowledge and reasons were combined. The option probability curve responses identified the students' misconceptions that were further investigated by interviews. PhET Interactive Simulations require improvements or additional features to help students better understand conceptual understanding through analogies of product and reactant molecules' movement in the equilibrium system.

Keywords **–** Chemical equilibrium, Conceptual understanding, Misconceptions, PhET interactive simulations, Rasch measurement model.

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1. Introduction

Chemistry is the study of matter and the changes it undergoes. Learning chemistry is challenging because its many abstract concepts are difficult to understand. Chemistry requires the ability to relate and experience the sub-microscopic, macroscopic, and symbolic levels of representation (Johnstone, 1991). The chemistry phenomenon can be observed at the macroscopic level, but the explanation is often at the sub-microscopic level. In addition, it is also represented at the sub-microscopic level symbolically, and there is no way to observe the atomic/molecular changes (Petillion & McNeil, 2020). Therefore, students cannot directly experience and see the sub-microscopic level, making it difficult to visualise a reaction (Abdoolatiff & Narod, 2009; Salame & Makki, 2021). In the end, students will construct their new knowledge with their previous prior knowledge (Üce & Ceyhan, 2019). However, if the new knowledge does not support existing prior knowledge, students tend to reject it (Ealy, 2018; Sewell, 2002).

Students create their understanding, based upon the interaction of what they already know and believe, and the phenomena or ideas they encounter (Gold-Veerkamp, Abke & Diethelm, 2017). Some studies have proven that students' prior knowledge cannot be accepted scientifically (Cakmakci, 2010; Palmer, 2001; Simonsmeier, Flaig, Deiglmayr, Schalk & Schneider, 2022; Taber, 2002), though that it plays a role in the foundation on which they build new information. Students' concepts that differ from scientific views are called misconceptions (Versteeg, Wijnen-Meijer & Steendijk, 2019). Despite misconceptions often being overlooked by teachers, they significantly influence the way students construct scientific knowledge to inform their understanding and improve the quality of further learning. A consequence of having misconceptions is that students experience difficulties when learning (Treagust, Nieswandt & Duit, 2000; Tümay, 2016). Misconceptions compromise learning, especially for meaningful learning. More than just memorising facts, it occurs when students make connections and relate between new knowledge and prior knowledge (Kumandaş, Ateskan & Lane, 2019). However, students find it challenging to connect them.

In Indonesia, chemical equilibrium is introduced in high school at grade 11 under the Regulation of the Minister of Education and Culture of the Republic of Indonesia number 37 of 2018, in the Basic Competencies of 2013 Curriculum No. 3.8; 3.9; 4.8; and 4.9 (Kemendikbud, 2018). The chemical equilibrium topic includes understanding the concept of equilibrium, Le Chateliers' principle, the equilibrium constant, homogeneous and heterogeneous equilibrium, and the effect of catalysts on equilibrium systems. Because of the importance of this topic, students are expected to master the concepts at a high level.

The concept of chemical equilibrium is one of the prerequisites for understanding several other concepts such as solubility, phase change, and acidity. Despite being one of the most important chemistry concepts in the curriculum, students find it challenging to construct the concept of chemical equilibrium (Üce & Ceyhan, 2019; Ulinnaja, 2019). Because molecules are not visible and the concepts can be abstract, it is difficult for novices to visualise and make connections involving the sub-microscopic level with observable macroscopic (Salame & Makki, 2021; Taber, 2013; Talanquer, 2011). Since students develop most of the misconceptions about chemical equilibrium due to their inability to visualise the level in the equilibrium state, it should be appropriate for teachers to use interactive simulations to describe the direction of reactants and products movement.

Animation and simulation play an essential role in visualising the sub-microscopic level (Falvo, 2008; Fang & Guo, 2016; Liu, Lin, Hsu, Hsu & Paas, 2021). Physics Education Technology (PhET) Interactive Simulations are used in this study to determine how deep the level of students' understanding after the equilibrium state is visualized and find students' misconceptions that may occur. The amount and style of guidance provided by the instructor and supporting materials are key factors in how simulations are used and perceived by students (Akaygun & Jones, 2014). In addition, the effectiveness of teaching also depends on the quality of the simulation design. The availability of text, audio, and layout affects different types of representation. These simulations have been used widely in chemistry education because they have the advantage of being free and easily accessible online. Interactive simulations can provide dynamic access to multiple levels of representation, thereby making visible objects that could not be directly observed by the eye (Ganasen & Shamuganathan, 2017; Moore, Chamberlain, Parson & Perkins, 2014; Watson, Dubrovskiy & Peters, 2020).

Because of the student inability to visualise the sub-microscopic entities, interactions, and behaviours, the researchers were motivated to investigate the use of PhET Interactive Simulations to describe an equilibrium system. Previous studies have touched on simulations as a learning medium for chemical equilibrium with misconceptions only analysed with the classical score theory in the form of percentages. In this study, the Rasch measurement model has been used for the item and student analysis to ensure that the prevalence of misconceptions is precise and accurate. The probability curve response for each option is also identified (Herrmann-Abell & DeBoer, 2011; Laliyo, Botutihe & Panigoro, 2019). The results will identify student misconceptions and help teachers improve the subsequent learning process (Sumintono & Widhiarso, 2015).

This study's objectives were to analyse student conceptual understanding about chemical equilibrium once employed PhET interactive simulations in learning. This study was conducted for three reasons. First, students have difficulty connecting sub-microscopic, macroscopic, and symbolic level. Second, students have different prior knowledge based on their everyday life experiences and perceive this as a scientifically acceptable concept. Third, students have difficulty visualising the chemical equilibrium system as well. Thus, this study specifically answered: "Do students have a good understanding of the chemical equilibrium concept with PhET interactive simulations?".

2. Background Literature

2.1. Misconceptions about Chemical Equilibrium

Misconceptions and their relation to learning difficulties have become a significant concern in chemistry education research (Teo, Goh & Yeo, 2014). Teachers cannot prevent students from being misconceptions because their prior knowledge influences it. However, teachers still struggle to help students overcome their misconceptions. Students often develop alternative ideas such as chemical changes, particulate properties of matter, solubility, and even chemical equilibrium that are far from being scientifically acceptable (Derman & Ebenezer, 2020; Pinarbasi & Canpolat, 2003). Teachers should identify student misconceptions in previous lessons before learning to transform them into scientific concepts first (Halim, Yong & Meerah, 2014).

Some common misconceptions that experienced by students in equilibrium reactions are that the reaction will occur after all reactants have reacted (Özmen, 2008; Usu, Rahmanpiu & Murhadi, 2019) such as irreversible reaction. Some even thought that no reaction occurs in the equilibrium system (Demircioğlu, Demircioğlu & Yadigaroğlu, 2013; Heeg, Bittorf & Schanze, 2020; Özmen, 2008). An accurate and complete understanding of the concept is essential for introducing other concepts. Therefore, identifying the barriers to understanding requires more in-depth investigation.

Misconceptions arise when students make assumptions that increasing the concentration of the reactants will form more reactants (Kurniawan, Rahayu, Fajaroh & Almuntasheri, 2020) and/or that the addition of solvents, such as water, will not affect the equilibrium shift (Al-Balushi, Ambusaidi, Al-Suhaili & Taylor, 2012). These common misconceptions indicate that students do not adequately apply Le Chateliers' principle.

Misconceptions related to temperature changes and reaction enthalpies were also observed in previous studies. Students did not understand the meaning of enthalpy in the reaction equation and temperature given to the system (Indriani, Suryadharma & Yahmin, 2017). Students ignored any temperature changes that could impact the distribution of the product and reactant molecules (Ganasen & Shamuganathan, 2017; Siswaningsih, Nahadi & Widasmara, 2019; Yan & Subramaniam, 2018).

An equilibrium reaction occurs in two directions. The forward reaction rate refers to the formation of products, while the reverse reaction rate refers to the reactants. Students assumed that the forward reaction and reverse reaction occurred at different rates after reaching equilibrium. Moreover, students believe that there are equal concentrations (or amounts) of reactant and products (Demircioğlu et al., 2013; Heeg et al., 2020; Jusniar, Effendy, Budiasih & Sutrisno, 2020; Üce & Ceyhan, 2019).

Numerous misconceptions were found in previous studies related to changes in the equilibrium constant. Students assume that changes in concentration (products or reactants), volume, and pressure will affect the shift in equilibrium (Ganasen & Shamuganathan, 2017; Özmen, 2008; Siswaningsih et al., 2019; Usu et al., 2019) which suggest this concept needs to be emphasised in chemistry classes.

The addition of a catalyst to the equilibrium system often causes misconceptions. Once a catalyst is added to the equilibrium system, the product or reactant concentration will change. The same is also true for the forward and the reverse reaction rates (Al-Balushi et al., 2012; Ganasen & Shamuganathan, 2017; Heeg et al., 2020; Jusniar et al., 2020; Özmen, 2008; Siswaningsih et al., 2019; Üce & Ceyhan, 2019; Voska & Heikkinen, 2000). This misconception reflects an incomplete understanding of how concentration and reaction rate after adding a catalyst in the equilibrium system.

Research indicates that students believe Le Chateliers' principle can be applied to all systems, including heterogeneous equilibrium systems, regardless of constant solids concentration (Banerjee, 1991; Heeg et al., 2020; Kousathana & Tsaparlis, 2002; Yan & Subramaniam, 2018). The addition of solids on the reactant side will shift the equilibrium towards more products (Banerjee, 1991; Jusniar et al., 2020; Kousathana & Tsaparlis, 2002; Kurniawan et al., 2020). Students often do not consider the concentration of added substances and the heterogeneous equilibrium system (Heeg et al., 2020; Indriani et al., 2017).

Based on the research results into common misconceptions in chemistry education, it is widely recognised that understanding (1) the approach of equilibrium, (2) Le Chateliers' principle, (3) equilibrium constant, (4) heterogeneous equilibrium, and (5) the effect of catalyst. In order to explain chemical equilibrium reactions, students must be able to apply three levels of understanding chemistry to it. For example, at the macroscopic level, students observe a colored solution, then after being given a particular treatment, the solution changes to a different color. It turns out that the shift of particles in solution towards the formation of products or is the cause. Students can only see the sub-microscopic level through the visualisation of the PhET Interactive Simulation. Furthermore, students can predict which direction the particles tend to move to reach an equilibrium state at the symbolic level through the simulations' reaction equation.

2.2. Animation and Simulation in Chemistry Learning

Animation and simulation, such as interactive visualisation, have an attractive and exciting appearance for students and teachers. Both are the best ways to encourage the students to put more extensive and better efforts into their visual concepts' explanations. Animation, being visually appealing, helps the students learn a great skill for the future. The animation for educational purposes also makes a class lively, lets the students absorb knowledge faster, encourages a child to explore a subject with full enthusiasm. Students are allowed to study and analyse critical teaching problems. Simulation creates interest and enhances active participation. As a result of role-playing, it helps develop critical thinking in student-teachers (Atabhotor & Kofoworola, 2020). Some studies have reported an increase in the development and use of simulations in chemistry learning (Bellou, Papachristos & Mikropoulos, 2018; Edwards, Bielawski, Prada & Cheok, 2019; Penn & Ramnarain, 2019).

The simulations used for this research were developed by the University of Colorado Boulder and sourced from the PhET website (http://phet.colorado.edu). PhET was created by a group of content experts, educators, interface design experts, and professional software developers. Since 2000, PhET has developed many interactive simulations for learning science including one for chemistry. PhET was created with pedagogical objectives that support students in scientific exploration, develop conceptual understanding, link simulations to everyday life, and view science as an engaging and fun subject (Moore et al., 2014). PhET covers topics ranging from sub-atomic particles to chemical dynamics through interactive representations. Simulations allow students to explore complex chemical phenomena and multiple representations spanning the sub-microscopic, symbolic, and macroscopic levels.

Interactive simulation is considered a helpful tool for improving student understanding (Moore et al., 2014). PhET constructs a causal relationship with a phenomenons' occurrence and helps students to engage with content (Ganasen & Shamuganathan, 2017; McKagan, Perkins, Dubson, Malley, Reid, LeMaster et al., 2008). PhET allows students to visualise at the sub-microscopic level. Most students report having positive learning experiences using interactive simulation (Correia, Koehler, Thompson & Phye, 2019) through increased knowledge, self-confidence, and conceptual understanding (Watson et al., 2020). PhET explains complex matters (Clark & Chamberlain, 2014) and helps change misconceptions into scientific concepts by developing mental models. Students can then connect the macroscopic, sub-microscopic, and symbolic levels of understanding they were previously unaware of (Niroj & Srisawasdi, 2014). PhET also helps increase student confidence in understanding questions, their success in solving problems, and trust in their ability to solve similar problems (Hansen, Moore & Gordon, 2015). Special features such as visual, audio, and text representations motivate students to use the simulations to learn chemistry (Clark & Chamberlain, 2014).

However, animations and simulations in learning have some drawbacks that can also present misconceptions: students cannot experience an event in a real environment, so it is lack of realism (Sadideen, Hamaoui, Saadeddin & Kneebone, 2012), because students have the flexibility of time to think and react in problem-based scenarios, there is no stress to think quickly as in real situations (Skulmowski, Nebel, Remmele & Rey, 2021), and once compared to laboratory experiments, simulations are only able to show pre-programmed results, and can only be manipulated to a certain extent. In addition, students cannot do much to develop their skills to handle lab equipment (Karlsson, Ivarsson & Lindström, 2013).

3. Methodology

3.1. Methods

3.1.1. Participants

A total of 108 students grade-11 from one Indonesian secondary school were selected to meet the minimum sample size required and a stable item calibration in the Rasch measurement model (Linacre, 1994).

3.1.2. Research Design

This research used a descriptive quantitative method to explain information in facts, characteristics, or relationships between the investigated variables. The method included a survey with a cross-sectional design, a procedure in managing a survey or questionnaire to a sample or population to describe its characteristics at one point in time (Creswell, 2012).

Students were presented with PhET Interactive Simulations while studying chemical equilibrium. The students completed the Chemical Equilibrium Diagnostic Instrument (CEDI) test after the lesson. The study was completed over three weeks, with two online meetings held each week, as shown in Figure 1.

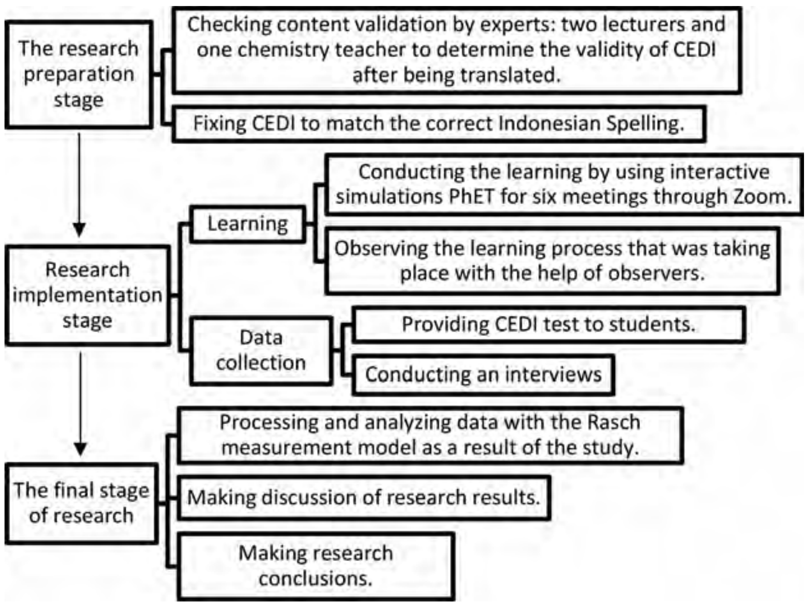

Figure 1. Research and learning procedures

3.2. Intruments

3.2.1. Chemical Equilibrium Diagnostic Instrument (CEDI)

The CEDI developed by Özmen (2008) and used in this study consisted of 13 items in two tiers. The first-tier consisted of a content question in multiple-choice format with three choices. The second-tier consisted of four possible reasons for answering the first part with three wrong reasons and one right reason. Both tiers had only one correct answer. The primary criterion for designing each item was that students could determine content knowledge at the first-tier with a reasonable explanation at the second-tier. Misconceptions were identified by combining answers from both tiers. If the student answered both tiers correctly, they were considered to have a good understanding of the concept. Conversely, if students answered only one of the levels correctly, they were considered to have misconceptions. Wrong answers at both levels were interpreted as students not understanding the concept (Özmen, 2008; Supatmi, Setiawan & Rahmawati, 2019; Usu et al., 2019).

CEDI consist of five alternative conceptions, including equilibrium, application of Le Chateliers' principle, the equilibrium constant, heterogeneous equilibrium, and catalysts' effect, are shown in Table 1. Participating students were asked to answer all the questions on the measurement instrument in less than 90 minutes, which is the standard duration for online learning.

Before CEDI was given to students, it was translated from English to Indonesian after which three experienced validators tested that validity in term of language had been maintained. The literature indicates the advantages of using a two-tier test that many previous studies have used (Chandrasegaran, Treagust & Mocerino, 2007). A two-tier test can determine the correspondence between students' conceptual and procedural knowledge (Peterson et al., 1989) and test almost any conceptual understanding that visualised by PhET.

Chemical equilibrium concept	Item number	Alternative conceptions
Approach of Equilibrium	Q3	Forward and reverse reaction rates
	Q7	The concentration of the reactants after reaching an equilibrium state
	Q8	The approximate concentration of the product after reaching the equilibrium state
Le Chateliers' principle	Q4	Effect of changes in substance concentration
	Q12	Addition of a substance to the same substance, with each substance, also having the same concentration.
	Q13	Effect of temperature changes on the equilibrium system
Equilibrium constant	Q1	Equilibrium constant once the system temperature is kept constant
	Q5	Effect of raised temperature on exothermic reactions
	Q11	Effect of the initial concentration of the reaction on the equilibrium constant
Heterogenous equilibrium	Q2	Decrease of solids on equilibrium shifts
	Q9	Addition of solids to the equilibrium shift
The effect of catalyst	Q6	Forward and reverse reaction rates
	Q10	The approximate concentration of the product after reaching the equilibrium state

Table 1. Areas of alternative conceptions

3.2.2. Interviews

Interview questions were distributed after student finished filling out the CEDI test; both are shared through Google Forms. Interviews were conducted to determine the participants' impressions of using PhET Interactive Simulations in their learning. The interview guidelines consisted of five open-ended questions: why they are attracted to chemistry, the characteristics of chemistry subjects, what students learned from PhET Interactive Simulations, students' explanation regarding five concepts of chemical equilibrium, and their opinion on how much impact the simulation had on conceptual understanding. This data was used for supporting information.

3.3. Procedure for Data Analysis

3.3.1. Rasch Measurement Model

The Rasch measurement model was used to analyse the field test data. The probability of a student responding to each correct item was determined by the difference in the overall level of student performance and the difficulty level of the item, according to the following equation:

$$ln\left(\frac{P_{ni}}{1-P_{ni}}\right) = B_n - D_i$$

P_{ni} is the probability that student n with the overall ability level B_n will respond correctly to item i with difficulty D_i. Whereas $1 - P_{ni}$ is the probability that students do not answer the same items correctly (Boone, Staver & Yale, 2014). Probability can simply be written as: Probability of answering correctly = student performance – item difficulty level (Sumintono & Widhiarso, 2015).

The student B_n and item D_i measure are expressed on the same interval scale and independent of each other. The student performance level and item difficulty level are measured in logarithm units called log odds ratio or logit, varying from $-\infty$ to $+\infty$. The mean logit was set at 0.0, with a positive logit indicating a higher than average estimate and a negative logit indicating a lower than average estimate (Boone et al., 2014).

CEDI items were assessed using the scheme suggested by previous research (Lu & Bi, 2016). Each CEDI item scores one point if both levels are answered correctly. However, if one of the levels is answered incorrectly or both of them are answered incorrectly, then it is given a score of zero points. Therefore, the raw data value is a dichotomy (1 and 0). The total CEDI for each student was calculated and processed with the Winsteps 4.0.1 software.

The Rasch measurement model is used to determine the instrument's unidimensionality and local independence, the students' performance to the difficulty level of the items, options probability curve analysis, wright map analysis, and graph analysis of the measurement information function. Besides, the percentage of students holding misconceptions was also identified.

3.3.2. Coding Data

Interview data from video recordings were converted into sentences that matched the actual data so that there was no change. Each subsequent interview data was given a unique code, for example, 01C5. Numbers 01 and 5 were the attendance and classroom numbers, respectively, while, C stood for Chemistry. Compaction of facts was done by changing the interview transcripts into simple sentences. If all data was compacted and interpreted, similar facts were collected. The goal was to systematise categorisation to eventually find key themes as material for a data narrative. Categorisation represented the conclusion of analysis after the researcher identified a collection of facts and the interrelationships between them. In broad and in-depth facts, categorisation gave rise to sub-categorisation (coding) variances where the primary needs were chosen, and the most important categorisations to answer the research problem were used (Creswell, 2012; Mahpur, 2017). A sub-category is a branch of a category, which category is a general collection of facts. The number of categories and sub-categories depends on the response of the research sample. The more varied the responses obtained, especially those needed to answer the research objectives, the better to support quantitative data.

4. Results

This study aims to analyse student conceptual understanding about chemical equilibrium using Physics Education Technology (PhET) Interactive Simulations. Referring to these objectives, here is a description of the results of this study.

4.1. Dimensionality and Local Independence Tests

Two basic assumptions, unidimensionality and local independence, are evident when using the Rasch measurement model to analyse data.

Table 2 shows that the CEDI instrument used in the study met with unidimensional assumptions because a test measures only one dimension if the value of Raw Variance explained by the measure is more than 30% (Linacre, 1998; Rahayu, Putra, Iriyadi, Rahmawati & Koul, 2020), or, according to other literature, 20% (Sumintono & Widhiarso, 2014). The CEDI instrument measures above the minimum required value of 33.7% and the Unexplained Variance analysis results do not exceed 15%, a proof of unidimensionality (Ardiyanti, 2017; Sumintono & Widhiarso, 2014). Local independence will automatically follow unidimensionality (Naga, 2012; Sudaryono, 2011) so that if the unidimensional value is met, the assumption of local independence can also be assumed.

	Item Information Units		
Standardized Residual Variance	**Eigenvalue**	**Observed**	**Expected**
Total raw variance in observations	19.6059	100.0%	100.0%
Raw variance explained by measures	6.6059	33.7%	33.2%
Unexplained variance in 1st contrast	2.2167	11.3%	17.1%
Unexplained variance in 2nd contrast	1.7793	9.1%	13.7%

Table 2. Variance of standardized residual

4.2. Instrument Analysis

In Rasch modelling, summary statistics provide information about the quality of the overall student response pattern, the quality of the instruments used, the interactions between students and the items, and the students' ability to respond to the difficulty level of the items.

					INFIT		OUTFIT	
Result	**Total Score**	**Count**	**Measure**	**Model S.E.**	**MNSQ**	**ZSTD**	**MNSQ**	**ZSTD**
Mean	5.5	13.0	-0.41	0.69	1.00	0.0	1.00	0.0
P.SD	2.0	0.0	0.95	0.06	0.37	1.2	0.58	1.0
S.SD	2.0	0.0	0.96	0.06	0.37	1.2	0.58	1.0
Max.	11.0	13.0	2.22	1.11	2.23	2.9	3.80	3.0
Min.	1.0	13.0	-3.15	0.65	0.43	-2.3	0.37	-1.8

Real RMSE 0.75 True SD 0.60 Separation 0.80 Person Reliability 0.39

Table 3. Summary of measured person

The person measure value in Table 3 shows the average value of the overall student performance in working on the items is -0.41 logits, a value smaller than 0.00 logits. This indicates that the students' average ability is lower than the difficulty level of the items. In addition, the value of person reliability is 0.39, which means the students' consistency of answers is low. One factor can be caused by misconception (Kaltakci-Gurel, Eryilmaz & McDermott, 2017; Ntshalintshali & Clariana, 2020). Even so, the MNSQ Infit and MNSQ Outfit values are 1.00. The ZSTD infit and the ZSTD outfit values are 0.0. The expected values of the MNSQ and ZSTD are 1.0 and 0.0, respectively. This value showed an excellent data category. Besides, the separation value is 0.80. One group of students based on the separation of strata (Bond & Fox, 2015; Sumintono & Widhiarso, 2015).

Table 4 shows the value of the item reliability of 0.96, which indicates that the quality of the items in the CEDI instrument is a special data category. The MNSQ Infit and MNSQ Outfit values are 0.99 and 1.00. The ZSTD infit value and the ZSTD outfit are -0.2 and 0.0. This value is also included in the reasonably good data category. The separation value is 5.00. Seven groups of items can be interpreted as questions that are the most challenging, challenging, quite challenging, medium, quite easy, easy, and the easiest (Bond & Fox, 2015; Sumintono & Widhiarso, 2015).

Results	Total Score	Count	Measure	Model S.E.	INFIT		OUTFIT	
					MNSQ	ZSTD	MNSQ	ZSTD
Mean	46.1	108.0	0.00	0.25	0.99	-0.2	1.00	0.0
P.SD	25.3	0.0	1.31	0.04	0.20	1.7	0.35	1.7
S.SD	26.3	0.0	1.36	0.04	0.21	1.8	0.36	1.8
Max.	93.0	108.0	2.00	0.33	1.56	4.3	2.00	4.8
Min.	12.0	108.0	-2.51	0.21	0.77	-2.7	0.63	-2.1

Real RMSE 0.26 True SD 1.28 Separation 5.00 Item Reliability 0.96

Table 4. Summary of measured item

4.3. Item Analysis

Item analysis provided two pieces of information; the level of difficulty of the items and the items' fit with the Rasch measurement model.

In Table 5, the items have been sorted from the highest to lowest difficulty level. In this case, item 12 has the highest difficulty level of 2.00 logits, while item 2 has the lowest difficulty level of -2.51 logits. The table shows that item 8 does not meet the three expected value intervals of Outfit MNSQ (0.5-1.5), Outfit ZSTD (-0.2-0.2), and PTMeasur Corr (0.4-0.85) (Boone et al., 2014). This data means that the twelve items have an adequate validity level. If an item did not fit with the model, students were considered to have misconceptions or they did not understand the item's concept (Sumintono & Widhiarso, 2015). A more in-depth analysis of item Q8 is required for further investigation.

Item	Total Score	Measure	INFIT		OUTFIT		PTMeasur	
			MNSQ	ZSTD	MNSQ	ZSTD	Corr.	Exp.
Q12	12	2.00	1.14	0.6	1.30	0.9	0.19	0.33
Q1	15	1.71	0.77	-1.2	0.63	-1.2	0.55	0.35
Q5	20	1.31	0.79	-1.3	0.71	-1.2	0.56	0.37
Q11	24	1.04	1.03	0.2	1.05	0.3	0.34	0.38
Q6	30	0.69	0.94	-0.5	0.83	-1.0	0.46	0.38
Q8	31	0.63	1.56	4.3	2.00	4.8	-0.22	0.39
Q10	42	0.09	0.89	-1.4	0.84	-1.4	0.50	0.39
Q13	57	-0.57	0.83	-2.7	0.78	-2.1	0.54	0.37
Q3	62	-0.79	1.14	1.9	1.15	1.2	0.23	0.37
Q4	65	-0.92	0.91	-1.2	1.04	0.4	0.43	0.36
Q9	72	-1.24	0.90	-1.1	0.81	-1.2	0.45	0.34
Q7	76	-1.44	1.04	0.4	1.15	0.9	0.27	0.33
Q2	93	-2.51	0.94	-0.2	0.75	-0.7	0.34	0.26

Table 5. Item measure

4.4. Wright Map Analysis

Figure 2 shows the distribution of student abilities and the level of difficulty of the items on the same scale. It can be observed that the student's average ability (-0.41 logits) is lower than the average item difficulty (0.0 logits). Some students were outliers with abilities either far above the logits average (16K3, 22K5, 31K2, 32K5, and 34K2) or far below (14K5). It is critical for teachers to understand this issue because misconceptions can occur in all ability categories: low, medium, and high (Adeniji, 2015; Hakim, Kadorahman & Liliasari, 2012). Item Q8 has a difficulty level similar to item Q6, however item Q8 should still be relatively accessible for students to answer more effectively than Q11, Q5, Q1, and Q12.

Most students could not answer items Q12, Q1, Q5, and Q11 correctly (based on the wright map and item measure about 1.04 logits-2.00 logits). The two possible reasons for this outcome are that students have misconceptions about the concepts visualised by the PhET Interactive Simulations or they did not understand the concept due to the simulation's limited features.

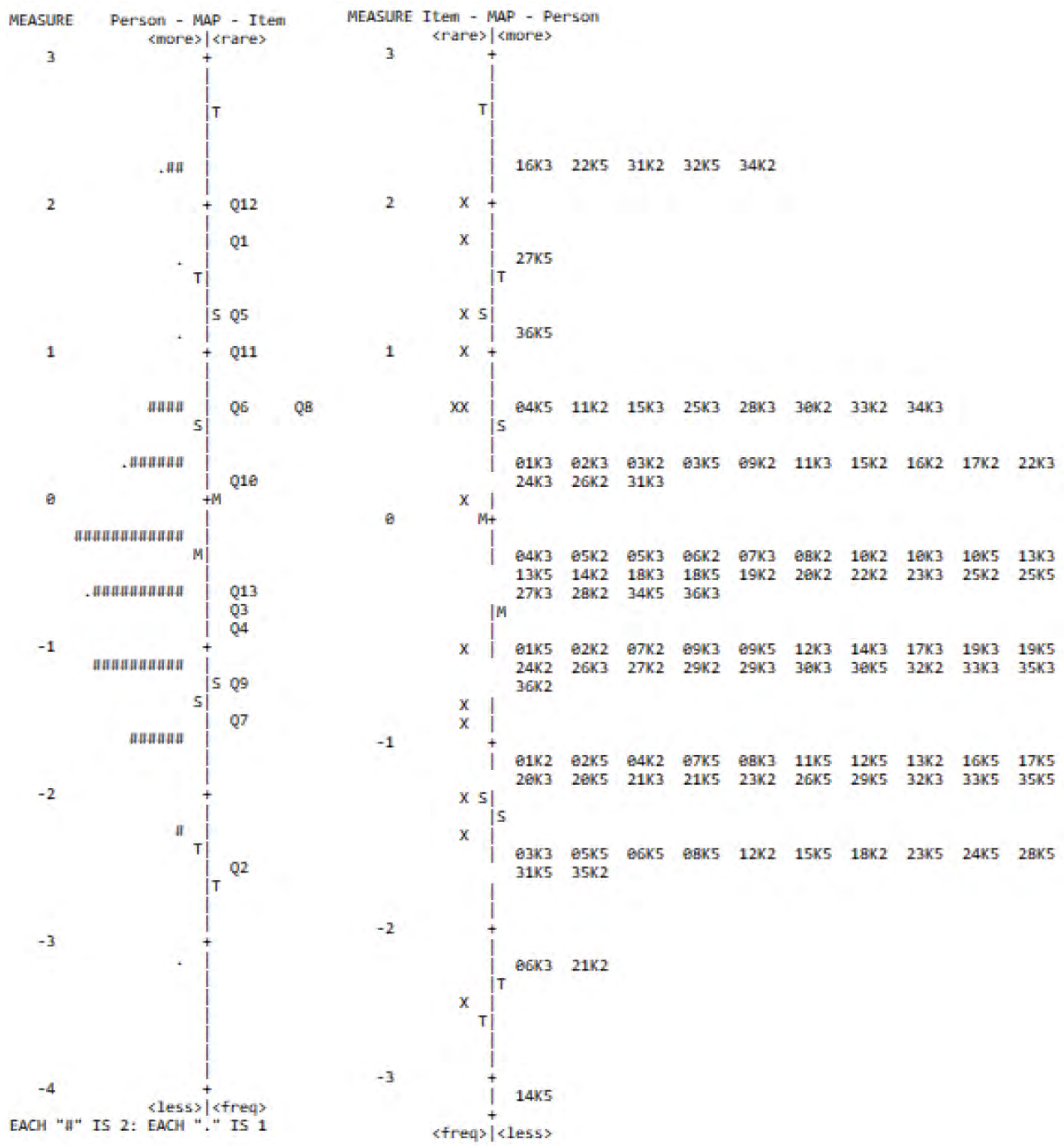

Figure 2. Wright map

Item Q12 tests students' understanding of the application of Le Chateliers' principle of adding the same concentration of substances as the original solution. Q12 items cannot be displayed in PhET Interactive Simulations due to its limited features. Results show that students were less likely to have a sufficient conceptual understanding of the PhET Interactive Simulations rather than to experience misconceptions. A total of 61.2% of students did not understand the concepts and probability curves of the item Q12 options.

Item Q1 refers to the equilibrium constant once the system temperature is kept constant. This concept also cannot be presented with PhET Interactive Simulations. Responses showed that students tend not to have a complete understanding of the concept rather than misconceptions. A total of 84.3% of the students proved that they did not understand the concepts and probability curves of the Q1 options.

Item Q5 tested students' understanding of the equilibrium constant once the temperature was raised in an exothermic reaction. The response shown in item Q5 indicates that students have misconceptions. However, the large percentage of students who did not understand the concept is more significant than misconceptions. This interpretation is supported by the Q5 option probability curve because the students had good overall content knowledge but provided incorrect reasons.

Item Q11 refers to the effect of initial concentration to equilibrium constant. PhET Interactive Simulations cannot directly display *Q* and *K* values resulting in the majority of students, a total of 44.5%, not understanding the concepts and option probability curves rather than holding misconceptions.

Item Q2 tested the students' understanding of the heterogeneous equilibrium about the effect of decreasing solids. Although the PhET Interactive Simulations do not yet describe this system. A total of 84.3% of students understood the concept well, possibly because this topic was taught in the classroom by a law or a rule. The option probability curve supported this result from item Q2.

4.5. Graph Analysis of The Measurement Information Function

Figure 3 shows an X-axis of the students' abilities, while the Y-axis explains the magnitude of the information function. Based on these data, the items will get high information when given to students with moderate abilities which shows that the set item was moderately difficult (Sumintono & Widhiarso, 2015).

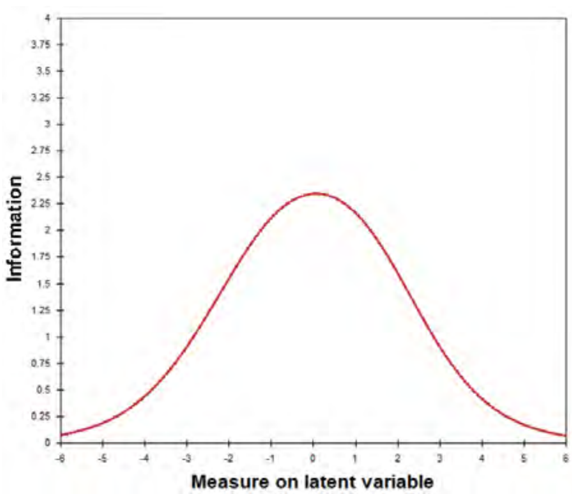

Figure 3. Graph of measurement information function

4.6. Student Interviews Analysis

The results of the interviews are divided into five data categories: students' motivation to learn chemistry, the characteristics of chemistry subject, students' experiences of learning with PhET Interactive

Simulations, chemical equilibrium learning without using the simulations, and the students' understanding of the chemical equilibrium concept. Then each category is broken down into several coding accordingly.

Interviews with students indicated that teachers motivated them to study and understand chemistry through influencing and conveying information during the learning process. Students were also interested in chemistry due to its relation to everyday life. Students assume that an understanding of chemistry can help them explain everything around them scientifically. Indonesia, along with many other countries, faces the challenge of shifting from a face-to-face learning environment to online learning. However, online learning can be an obstacle for some students trying to absorb subject matter. Therefore, it is crucial to analyse misconceptions to determine the optimal number of concepts students can absorb during online learning.

As noted by previous research, students experience difficulties navigating across those levels: the sub-microscopic (atoms, molecules, and ions), the macroscopic (elements, compounds, and chemical reactions), and the symbolic (symbols and the periodic table of elements) (Johnstone, 1991). In order to develop a meaningful understanding, students need to be able to navigate across these levels, as demonstrated in the following student interview:

> "*Chemistry has a very important position than other sciences because chemistry can explain sub-microscopic to macroscopic phenomena*." (Student 13C2)

Therefore, it is essential that a good understanding of basic concepts occurs first to understand subsequent concepts. Misconceptions will arise when students build new concepts based on an incorrect understanding of previous concepts. Chemistry is considered difficult to understand because it is complicated, abstract, and difficult to accept despite simplifying the actual state. As per the statements below:

> "*Chemistry is hierarchical. All concepts are related. If the basic concept is not understood, then it will be difficult to understand a new concept*." (Student 11C5)

> "*Chemistry is abstract, simplification of the actual situation, sequential and tiered, this subject is difficult for students including myself and others to learn*." (Student 18C5)

The use of PhET Interactive Simulations in chemistry provides students with a learning experience where they can explore concepts directly to gain knowledge and experiment in a relatively short time. Every teachers' explanation can be directly practiced and proven so that students understand a concept more quickly. As per the statements below:

> "*Learning with PhET interactive simulations makes it easier for students to be interested in learning by exploring directly and being able to experiment in a relatively short time*." (Student 06C2)

> "*...I also became more understanding, because every scientific explanation can be directly practiced through the media*." (Student 07C2)

Students consider this media suitable for online learning. PhET Interactive Simulations help students visualise the concept of chemical equilibrium (see Figure 4a and 4b). Students understand that molecules will move or shift anywhere to achieve an equilibrium state if given specific treatments. The number of molecules defines as the concentration of products or reactants. In the end, students know the factors that affect the shift in equilibrium. However, some students stated that it was difficult to understand the analogy used and using this simulation independently based on the interviews. As per the statements below:

> "*This simulation certainly helps. It makes it easier for me to understand that the molecule can move or move if given a certain treatment. To reach a state of equilibrium...*" (Student 22C5)

> "*I can find out the factors that affect the direction of the shift in the equilibrium*." (Student 21C2)

> "*I still do not understand the analogy used in these simulations*." (Student 07C5)

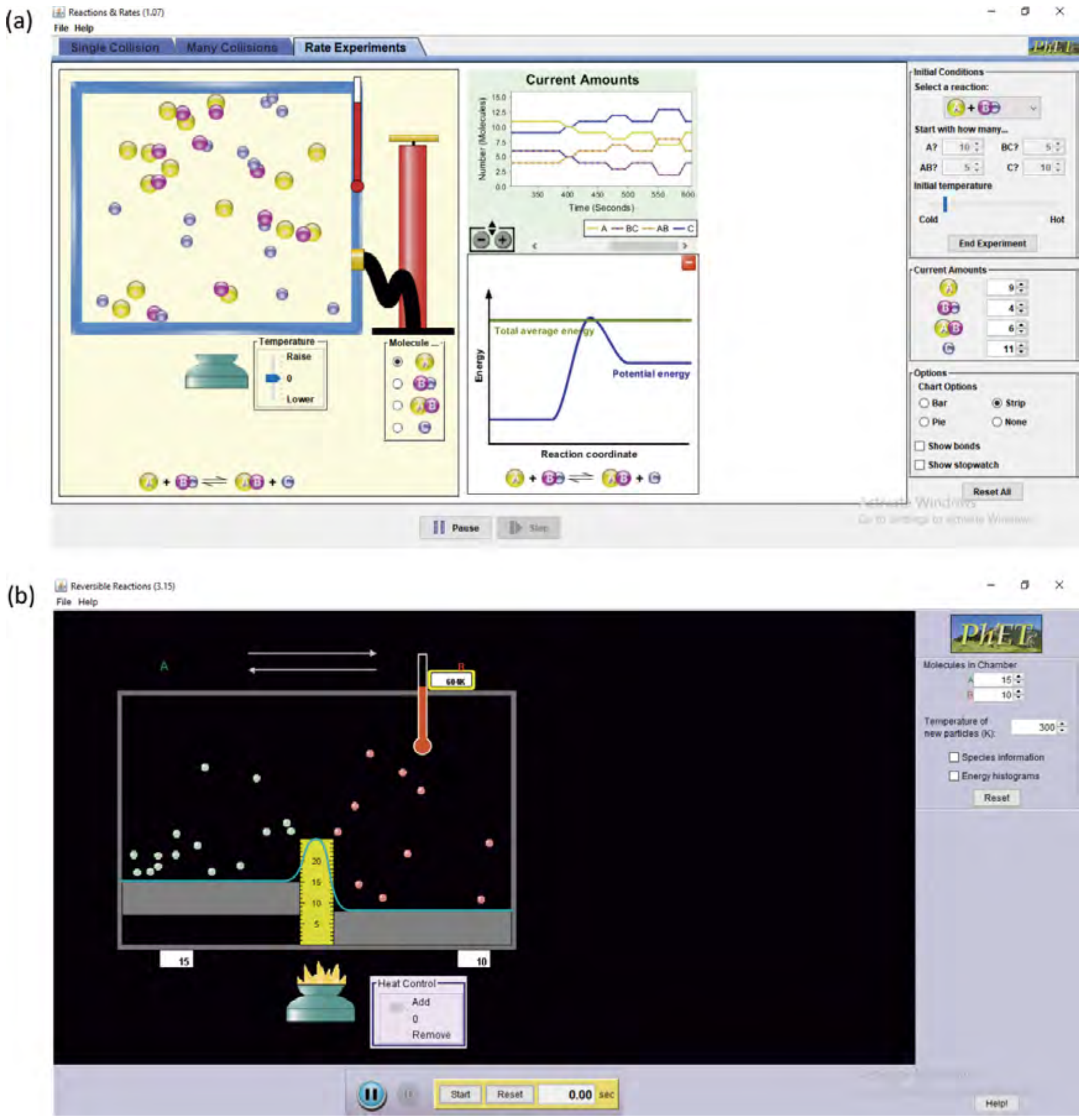

Figure 4. (a) Reaction & rates. (b) Reversible reactions

Students' concept interviews were also obtained. The results showed that there were no misconceptions about the equilibrium concept. In the concept of applying Le Chateliers' principle, a misconception was found when students were asked about temperature changes in the equilibrium system. Some students had misconceptions about the enthalpy relationship of reactions with different temperatures in the shift in equilibrium. Students could distinguish the value of the equilibrium constant (*K*) and the quotient reaction (*Q*). However, a misconception was found when students were asked the factors that can influence the *K* value. They answered four factors: changes in concentration, temperature, volume, and pressure. All students correctly answered the question about heterogeneous equilibrium concepts. They agreed that the addition or subtraction of solid did not affect the equilibrium shift. The effect of catalyst was the last concept discussed. Half of them had a misconception because the forward reaction rate became more significant than the reverse reaction rate. The research results showed that students have difficulty determining the effect of temperature on the shift in the direction of equilibrium and the equilibrium constant, and the catalyst's effect on the forward and reverse reaction rates.

5. Discussion

Option probability curves were used because they present a visual image of the distribution of correct answers and misconceptions across the curriculum concepts covered. They show if the shape of the curve matches the researchers' expectations or whether something unusual happens that could indicate a structural problem with a question. The shape of the curve can also show a hierarchy of misconceptions that decreases or increases in sequence as students become more knowledgeable about a topic. This paper presents an example of the option probability curve for a single item in our study (Figure 5).

Carbon monoxide and hydrogen react according to the following equation:

$$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(l)$$

When 0.02 M CO and 0.03 M H_2 are introduced into a vessel at 800 K and allowed to come to equilibrium, what can we say about the rate of reverse and forward reactions at equilibrium?

a) *the rates are equal
b) forward reaction rate is greater than the reverse one
c) reverse reaction rate is greater than the forward one

Reason:

1) forward reaction goes to completion before the reverse reaction starts
2) *the rates of the forward and reverse reactions are equal when the system reaches equilibrium
3) as time passes, the concentrations of products increase
4) at the beginning, the concentrations of the reactants are greater than the concentrations of products

*) Correct answer

Figure 5. Sample item 3 testing the idea about the equilibrium concept

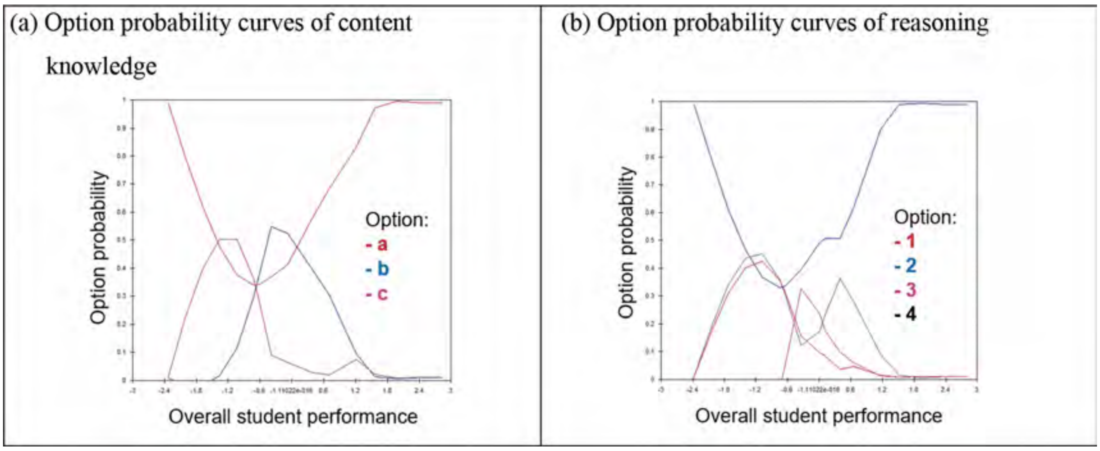

Figure 6. Corresponding option probability curves of (a) content knowledge and (b) reasoning

Item 3 (Q3) examines students' understanding of the equilibrium concept of the forward and reverse reaction rates. As shown in Figure 6a, students with a performance level of -1.2 logits are more likely to choose option c, which decreases with increased understanding of the topic. Students with a performance level of -0.6 logits are more likely to choose option b and decreases as option c. The probability of students choosing option b is higher than option c. Students who have a very low understanding of the topic, less than -2.4 logits, choose the correct answer in option a, even though the curve decreases to -0.6 logits. However, the curve increases again as the expected progression of understanding. If option b is compared to option a, the students' probability of choosing option a is more dominant than option b between -2.4 logits to 1.8 logits. This response pattern indicates that students have good content knowledge in item 3 overall. The results follow the expected development of understanding and corresponding to 58.3% of students who chose option a. The achievement of excellent content knowledge may occur because PhET Interactive Simulations can display the graphs of forward and reverse reaction rates which is proven to help students answer the first-tier in item 3. It proves that PhET helped students to engender their conceptual change by making connection between multiple representations in chemical equilibrium topic (Ganasen & Shamuganathan, 2017).

As shown in Figure 6b, students' probability of answering option 1 is higher than option 3, and both decrease as the increase of students' level performance. Option 4 is known to have a higher probability than options 1 and 3 over a specific range of logits. However, students with a performance level of -1.2 logits to 0.6 logits are more likely to choose option 4. The range is relatively large and includes the performance of students to choose options 1 and 3. Students with a performance level of fewer than -2.4 logits to 1.8 logits have the highest probability of choosing option 2. So, option 2 as the correct answer can be mostly understood by all students from very low to very high performance. The curve of option 2 has some similarities to option a. These results show that students have a good understanding of the overall concept of equilibrium in item 3. Students understand that when CO gases and H_2 gases concentrations are left in the equilibrium system, the reactant concentration will decrease to form the product. Simultaneously, the product will reform the reactant with the same rate of the forward and reverse reactions. This result is supported by all student responses who answered option a, accompanied by reason on option 2 of 56.5%. It suggests that students understand when a reaction is carried out in a closed reaction vessel at constant temperature, the system proceeds spontaneously toward equilibrium. Which the dynamic of equilibrium state is shown by the forward and reverse reactions continue to occur at equal rates after equilibrium is reached (Petrucci, Herring, Madura & Bissonnette, 2017).

Table 6 shows that 58.3% of students answered option a, the forward reaction rate will be the same as the reverse reaction rate, and 56.5% of students believed that these two reaction rates occur when the system reaches equilibrium in option a2. The percentage of students' misconceptions in options a1, a3, and c2 was only 0.9% of students, respectively.

Choice of first-tier	**Reason(%)**				**Total(%)**
	1	**2**	**3**	**4**	
a	0.9	56.5**	0.9	0	58.3*
b	5.6	0	12	19.4	37
c	0.9	0.9	1.8	0.9	4.5

*Correct content; **Correct content and reason.

Table 6. Percentage of each response combination for item 3 on CEDI

This misconception shows that the forward reaction rate towards product formation will be completed before the reverse reaction rate starts in option a1. The correct concept is an equilibrium reaction, including a dynamic reaction which means both reactions occur simultaneously so that when some products are formed some reactants are reformed at the same time. Therefore, the forward reaction rate is the same as the reverse reaction rate when it reaches equilibrium (Chang, 2010; Heeg et al., 2020; Usu et al., 2019). Another misconception is that the product concentration will increase over time in option a3. It is possible that students still think like a one-way reaction. This reaction is not possible due to the formation of more reactants from the products already produced. So, the product concentration always increases.

Some students considered the forward reaction rate and the reverse reaction rate occur with different rates (Demircioğlu et al., 2013; Üce & Ceyhan, 2019). A total of 37% of students had the wrong content knowledge because they chose option b. These findings indicate that students still did not understand the equality forward and reverse reaction rates when a reaction reaches the equilibrium state. Previous research has reported this problem (Heeg et al., 2020; Jusniar et al., 2020). The forward reaction rate is greater before equilibrium is formed but not right after equilibrium (Özmen, 2008). By contrast, 4.5% of students answered option c, and only 0.9% of students answered option c2 that the reverse reaction rate is greater than the forward reaction rate. Understanding of this process also needs to improve.

The relatively small percentage of misconceptions from 2.7% of students shows that PhET Interactive Simulations successfully improved understanding through the displayed reaction rate graph, allowing students to think about their prior knowledge and use it to correct misconceptions. PhET Interactive Simulations encourage students in hands-on activity by supporting them with the visualization, the guiding questions, combination of different features and instructional strategies, and guide them to understand the difficult concept with a simple explanation (Correia et al., 2019). These specifications helped students construct their knowledge by actively experiencing to connect the multiple representations (Ganasen & Shamuganathan, 2017). In this research, the equilibrium state is represented as a straight horizontal line on the graph (see Figure 4a), which indicates that the concentrations of reactants and products are continuously formed.

The results of the CEDI test on the five concepts of chemical equilibrium are shown in Table 7. The correct answers to content knowledge ranged from 11.1%-90.7% of students. However, once the answers were combined, responses decreased to 11.1%-84.3% of the students. This indicates that some students still had misconceptions.

Table 8 shows the twelve alternative conceptions identified through analysis of the CEDI items. These are grouped under each headings.

Based on the tendency analysis of misconceptions using the Rasch measurement model and the percentage of misconceptions, students with adequate content knowledge had two possibilities: they could choose either the right or the wrong reasons. Students who had the right reasons also had two possibilities: they could choose the right or wrong content knowledge to impact the emergence of misconceptions.

Option probability curves observed the students' thinking patterns in answering each item. Students had a good understanding of determining the forward and reverse reaction rates, reactants' concentration once it reached equilibrium, and solids' effect in the shift of chemical equilibrium system. A summary of students' understanding of the concepts is written as follows in Table 9. The table is divided into G (Good), LCK (Lack of Content Knowledge), LR (Lack of Reasoning), UC (Understand the Concept), M (Misconception), and DUC (Do not Understand the Concept).

	Correct response (%)	
Items	**Content choice**	**Combination**
Q1	13.9	13.9
Q2	86.1	84.3
Q3	58.3	56.5
Q4	63.9	59.3
Q5	20.4	16.7
Q6	36.0	28.7
Q7	72.2	71.3
Q8	28.7	28.7
Q9	64.8	64.8
Q10	39.7	37.0
Q11	54.6	21.3
Q12	11.1	11.1
Q13	90.7	51.8

Table 7. Percentages of content choice and correct combination

Alternative conceptions	Total (%)
Approach of Equilibrium	
The difference in the direction of the forward and reverse reaction rates	2.7
The concentration of the reactants after the product is formed in an equilibrium state once the temperature is constant	11.1
Application of Le Chatelier's principle	
Determining the direction of the shift in equilibrium due to the effect of increasing the concentration	10.1
Adding the same substance concentration to the same solution	27.7
Effect of increasing temperature in an equilibrium system on exothermic reactions	44.5
Equilibrium constant	
Determining the equilibrium constant at a constant temperature	1.8
Determining the equilibrium constant, once the system temperature is increased in an exothermic reaction	23.1
Effect of initial concentration on the equilibrium constant	34.2
Heterogeneous equilibrium	
Effect of decreasing solids on the equilibrium system	3.6
Effect of increasing solids on the equilibrium system	2.8
The effect of catalyst	
Effect of adding a catalyst on the difference in the direction of the forward and reverse reaction rates	62.8
The effect of adding a catalyst on the concentration of the product	18.4

Table 8. Percentages of students' alternative conceptions

Chemical equilibrium concept	Item number	Content knowledge	Reasoning	Understanding
Approach of Equilibrium	Q3	G	G	UC
	Q7	G	G	UC
	Q8	LCK	LR	DUC
Le Chateliers' principle	Q4	LCK	LR	DUC
	Q12	LCK	LR	DUC
	Q13	G	LR	M
Equilibrium constant	Q1	LCK	LR	DUC
	Q5	G	LR	M
	Q11	LCK	LR	DUC
Heterogenous equilibrium	Q2	G	G	UC
	Q9	G	G	UC
The effect of catalyst	Q6	LCK	G	M
	Q10	G	LR	M

Table 9. Summary of students' understanding of concepts

These results also explain that the students' understanding of concepts through PhET Interactive Simulations were less effective. For example, in the concept of heterogeneous equilibrium, students understood the concept well, even though these simulations does not provide visualisations. Students can only understand the concept with a clear understanding from the teacher. In the concept of Le Chateliers' principle (Q4 and Q12), students seem to have difficulty to understand the content, weak in reasoning, and do not have conceptual understanding. This finding is posibble to happen due to the lack of teacher's escort. The existing research on simulated-based learning found that simulation with limited teacher's guide tend to increase students' cognitive load which hinders meaningful learning (Correia et al., 2019; Kalyuga, 2011). However, the simulations helped students to imagine the concept of items Q3 and Q7. Students have visualized a system in a dynamic equilibrium state and learned to characterized it through various modes of equilibrium concepts. Thus, in this particular case, PhET Interactive Simulation enhanced students' understanding (Ganasen & Shamuganathan, 2017).

6. Conclusions

The results of the research show that some students still held misconceptions after using PhET Interactive Simulations. The percentage of students who answered correctly on content knowledge ranged from 11.1-90.7%. However, once the content and reason answers were combined, the percentage decreased to 11.1-84.3%. Based on the option probability curve response, students had a good understanding of the concept of items 2, 3, 7, and 9; misconceptions in items 5, 6, 10, and 13; and did not understand the concepts in items 1, 4, 8, 11, and 12. There were twelve misconceptions identified, as shown in Table 9.

The analysis of interviews about chemical equilibrium showed that students had difficulty determining: (1) the effect of temperature on the equilibrium shift and the equilibrium constant and (2) the catalyst's effect on the forward and the reverse reaction rates. There were several similarities with the results of the CEDI test. It is considered necessary to improve or add features to the simulations to help students gain a better understanding. While the simulations can visualise the concepts of items Q3 and Q7 students' understanding of concepts through PhET Interactive Simulations were still ineffective. The science teachers' role is still essential in helping students understand concepts.

Quantitative analysis with the Rasch measurement model revealed students' understanding of concepts and their misconceptions. The option probability curve illustrates that the prevalence of misconceptions can occur in all categories of students ranging from students with very low to very high performance. This information allows teachers to classify students' understanding based on their misconceptions and help them develop learning strategies. With the option probability curve for each item, an unusual response curve can be identified that indicates a problem with that item. Although this study does not answer why students experience specific misconceptions, a similar concept from different items has been created to help teachers diagnose students' thinking and understanding patterns so that chemistry learning becomes more effective and meaningful.

7. Implications for Teachers

The results of this study are expected to assist teachers in analysing student misconceptions that occur in learning about chemical equilibrium. The teacher can improve the learning process so that effective scientific explanations can help students to apply content knowledge correctly. PhET Interactive Simulations can help teachers to explain the concept of the equilibrium approach well. These simulations are beneficial for teachers when learning chemistry must be carried out online because it quite attracts students' attention to attend meeting invitations. In addition, simulation can also display experimental results quickly, so that is quiet efficient. Considerations such as the completeness of simulation features with the expected conceptual understanding as a target are necessary before learning.

8. Limitations and Future Research

Online learning limits teacher interaction with students as they find it hard to join Zoom due to internet connection constraints and limited meeting times. This situation disturbs the students' concentration when learning. Face-to-face learning is likely to positively affect students' understanding of the concept of chemical equilibrium.

Furthermore, it is suggested that learning chemical equilibrium using PhET Interactive Simulations should be developed further. An enhanced feature is that when the system temperature is changed, there is a column for the ratio of products to reactants once the equilibrium state is already reached, expressed directly as a value of *K*. Other than that, the temperature can be relatively constant. It is advisable to introduce students to the enthalpy graphs of exothermic and endothermic reactions before starting the experiment. While the features that can be added are the visualisation of heterogeneous equilibrium systems and the effect of adding a catalyst. Item Q8 requires further investigation due to limited simulation features. If only the chemical equilibrium simulation has been updated, the following research may test students' understanding of item Q8.

Further research is also suggested to use a three-tier or four-tier multiple-choice question test to obtain more in-depth analysis results with the Rasch measurement model in term of misconception. In addition, the teacher can improve student visualisation using the Conceptual Change Text (CCT) method.

Nevertheless, simulation in chemistry instruction has some limitations since it requires supervision by training personnel who are generally unavailable or not devoted to their duties. Simulation attempts to portray real situations in a simple way, which is very complex and challenging.

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