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Research Article:

Revealing Preservice Teachers' Conceptions, Troublesome Knowledge and Threshold Concept of Chemical Equilibrium through Predict Observe Explain Mental Model Diagnostic Test (POE-MMDT)

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ABSTRACT

The purpose of this study is to reveal preservice teacher' conception of chemical equilibrium concepts which then were further analysed to identify the troublesome knowledge and threshold concept of chemical equilibrium. The participants of this study were 68 preservice chemistry teachers from one of the Teacher Education Institutions in Bandung, Indonesia. Using the descriptive-qualitative design, this research uses a predict-observe-explain mental model diagnostic test consisting of four main questions related to the phenomenon equilibrium process of the decomposition of N_2O_4 to become NO_2. The findings show that most of the preservice teachers' conceptions about chemical equilibrium are at the level of partial understanding, with five misconceptions has been identified in this study: (1) the reaction in chemical equilibrium is the same as an irreversible reaction; (2) the concentration of reactant and products are the same at equilibrium state; (3) gas with a greater concentration at equilibrium state can be determined from the gas that was first inserted to the container; (4) the concentration ratio at equilibrium is equal with the ratio of the coefficient reaction, and (5) the reactant is the gas which fills the container first. Further analysis shows that there are eight concepts in chemical equilibrium with troublesome knowledge characteristics, namely (1) the concentration of reactants and products in a state of equilibrium; (2) changes in the concentration of reactants and products to a state of equilibrium when starting from any side; (3) reactions that occur in an equilibrium state, (4) chemical equations for equilibrium reaction; (5) the rate of reactions in equilibrium state; (6) the change of reaction rate to reach an equilibrium state; (7) the relationship between Q and K; and (8) the calculation of reactants and products concentration at an equilibrium state. In addition, chemical equilibrium has two threshold concepts: the dynamic characteristic of equilibrium reaction and equilibrium constant. These findings show that the predict-observe-explain instrument has the potential to disclose PSTs' mental model since it requires the participants to explain the prediction and its corresponding observation result. Besides, this instrument also guides the participants in explaining the macroscopic phenomena, which generates information about their understanding at the submicroscopic and symbolic levels. should be recognised as encompassed by and a form or part of "for all."

Keywords: Chemical equilibrium, conception, mental model diagnostic test, predict observe explain, threshold concept, troublesome knowledge

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INTRODUCTION

The Mental Model Represents The Understanding of Multiple Representations

A thorough understanding of chemical concepts necessitates knowledge of chemical concepts at each level of chemical representation, as well as the capacity to relate from one level to another (Chittleborough et al., 2002; Treagust et al., 2003; Akaygun, 2016). As a result, modelling in chemistry learning is a process of connecting analogue models, namely symbolic representations, with two target models, the sub-microscopic and macroscopic levels (Chittleborough & Treagust, 2007). According to Chittleborough et al. (2002), the three stages add to a person's understanding, which is reflected in his mental model. In other words, a person's mental model is formed through his understanding of a concept at three levels of chemical representation (Jansoon et al. 2009). The condition is in line with Sunyono et al. (2015), who discovered that learning with multiple representations is effective for developing mental models.

Mental models are representations of concepts in a person's mind used to describe and explain phenomena (Jansoon et al., 2009). In the chemistry context, the mental model connects and describes an understanding of a concept at the macroscopic, symbolic, and submicroscopic levels (Abd Halim et al., 2013; Supasorn, 2015). Information regarding mental models can also be utilised to determine additional learning strategies for students to acquire a meaningful understanding of chemistry concepts (Sunyono et al., 2015). Furthermore, the obtained mental model profiles can be utilised to examine threshold concepts and difficult information (Park & Light, 2009).

Troublesome Knowledge and Threshold Concepts as Barriers to Chemistry Learning

Park and Light (2009) stated that there are conceptual barriers to chemical concepts related to troublesome knowledge and threshold concepts. Perkins (1999) defines troublesome knowledge as counter-intuitive, alien, or incoherent knowledge. Perkins (1999) distinguishes six types of troublesome knowledge: Ritual Knowledge, Inert Knowledge, Conceptually Difficult Knowledge, Conceptually Difficult Knowledge, Alien Knowledge, Tacit Knowledge, and Troublesome Language. Ritual Knowledge appears to be utilised regularly in everyday life but has little meaning. Inert Knowledge happens *when students can learn scientific topics but do not establish many links to their daily lives.* Conceptually Difficult Knowledge is an issue in all courses, particularly mathematics and science. Alien Knowledge is knowledge gained from an opposed viewpoint to one's own. As a result, students will find it challenging to accept and believe the concepts presented. Tacit Knowledge defines a knowledge that is inconsistent, contradictory or has minor variations. Troublesome Language happens when an idea is expressed in numerous ways and languages, which may confuse pupils. Additionally, Park and Light (2009) also emphasise that troublesome knowledge can provide important information for recognising students' learning difficulties and finding an initiative to overcome these difficulties. Meanwhile, a threshold concept is a concept that, when mastered, can cause a transformation in a discipline's understanding. Students cannot fully understand the next concept without a threshold concept (Meyer & Land, 2003; Loertscher et al., 2014). When students understand the threshold concept, the core concepts will be easier and quicker to understand so that students can deepen their comprehension. Thus, if the threshold concept in a specific field has been identified, the curriculum can be reshaped to prioritise troublesome concepts so that students can learn more effectively and quickly (Land et al., 2005).

Many research studies have reported students' difficulties and misconceptions in various chemistry concepts in learning chemistry. These problems require an alternative approach and strategy to facilitate students in learning chemistry effectively. However, creating an alternative strategy for each chemistry concept will lead to a prolonged time consumption for chemistry curriculum implementation. Considering that chemistry concepts possess the properties related to the characteristics of troublesome knowledge, as Perkins (1999) mentioned, identifying troublesome knowledge and threshold concept in chemistry is essential to design an effective curriculum for students' chemistry learning.

Difficulties in Chemical Equilibrium

Chemical equilibrium has been considered one of the difficult topics in chemistry by students. Research studies reported that students have limited, inconsistent understanding and found several misconceptions about the concept of chemical equilibrium (Karpudewan et al.,). Misconceptions occur when the mental model that is built is inaccurate in describing the nature and relationships of entities (Vosniadou, 1994). Students' misconceptions that arise significantly affect subsequent science learning. In other words, defective ideas can hinder future learning (Taber, 2008). According to Park and Light (2009) students' misconceptions are caused by improper teaching, lack of prerequisite knowledge, and the absence of relevant concepts in long-term memory. In line with Wang and Barrow (2013), omitting one of the key concepts can lead to misconceptions. Misconceptions are highly difficult to remove from students' minds, thus hindering scientifically correct conceptual understanding. Therefore, it is important to identify students' misconceptions in chemical equilibrium topics to apply appropriate remedial treatment to equip them to understand the topic at a higher level better (Karpudewan et al., 2015; Sendur et al., 2011; Orgill & Sutherland, 2008; Voska & Heikkinen, 2000; Thomas & Schwenz, 1998).

Predict-Observe-Explain (POE) as An Instrument to Diagnose Students' Mental Model

Initially, POE was introduced by White and Gunstone (1992) as a learning strategy which involves students in predicting the experiment result, explaining their prediction, observing the phenomenon, and explaining the discrepancies between their prediction and observation. Therefore, the POE procedure is an effective strategy to elicit and encourage discussion of students' science conceptions during the learning process. These stages of POE are adopted as a diagnostic test by Sesen (2013). In the prediction stage, the participants write their prediction and explanation based on a short video presented by the instructor. In the observation stage, the participants watched a video that presented the full version of the phenomena. The participants were required to watch the video carefully and write their explanations. In the explanation stage, the participants must write their reasoning to explain any discrepancies between their prediction and observation. Students' responses at each stage of this instrument provide a profile of their mental model (Supasorn, 2015).

The difficulties in studying chemistry are not only experienced by students but also by teachers. In fact, to be able to design a well-planned chemistry lesson plan, a teacher must have a complete understanding of every chemical concept. At the Teacher Education Institution level, it is necessary to analyse preservice teachers (PST) conceptual understanding, troublesome knowledge, and threshold concepts as a source of information to overcome learning difficulties. The analysis can further be used as a basis for designing the learning process and developing learning media. In this study, the analysis was carried out through a predict-observe-explain mental model diagnostic test (POE-MMDT). Therefore, this study aims to obtain information about conception, troublesome knowledge, and threshold concepts on chemical equilibrium topics through a mental model diagnostic test in the form of predict-observe-explain (POE-MMDT) for chemistry preservice teachers. This aim is specified to answer the research questions:

1. How is preservice teachers' conception of chemical equilibrium topic based on their response to POE-MMDT?
2. How is preservice teachers' troublesome knowledge of chemical equilibrium topics based on their response to POE-MMDT?
3. How is preservice teachers' threshold concept on chemical equilibrium topic based on their response to POE-MMDT?

METHODOLOGY

This research uses descriptive qualitative research, which does not compare a variable with other variables, but explains the phenomenon as it is (Fraenkel et al., 2012). The study of these phenomena can be in the form of activities, characteristics, changes, relationships, similarities and differences with other phenomena. The phenomena in this study are in the form of conception, threshold concept, and troublesome knowledge of chemistry PST. In order to explore the threshold concept and troublesome knowledge in depth, it is necessary to have a conception from PST with different backgrounds. Therefore, this research was conducted in cross-sectional studies which collect data at one point in time from different levels of PST.

Participants

The participants in this study were 67 chemistry PSTs from the Department of Chemistry Education in one of the Teacher Education Institutes in Bandung, Indonesia. Participant recruitment is voluntary, and all participants have been informed and consented to their involvement in this study. The participant demographic is presented in Table 1.

Table 1. Demographic profile of participants

Level of PST	Number	Male	Female	Age	Number of units taken related to chemical equilibrium
Year 1	18	4	14	18–19	-
Year 2	15	2	13	19–20	2
Year 3	16	-	16	20–21	2
Year 4	18	2	16	21–22	3

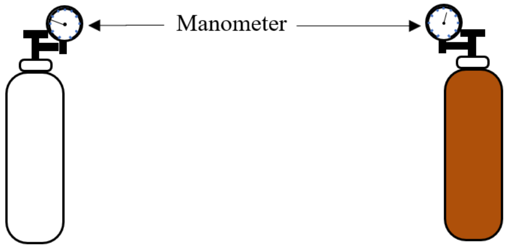
Based on the results of the curriculum structure analysis, some units in a curriculum discussed the topic of chemical equilibrium: Basic Chemistry 2 (Year 1, Semester 2), Physical Chemistry (Year 1, Semester 2), and School Chemistry (Year 3, Semester 5) unit. It means that PST Years 2 and 3 have studied chemical equilibrium in two units. Meanwhile, PST Year 4 has studied chemical equilibrium in 3 units. Since this research was conducted in the odd semester, PST Year 1 has not taken any unit related to chemical equilibrium. However, they must have experience learning chemical equilibrium in high school.

Instrument

The instrument used in this study is a POE-MMDT on chemical equilibrium material. The researchers consider the curriculum for preservice chemistry teacher education in developing this instrument. The content coverage is based on the multiple representation analysis results from ten Chemistry Text Books. The formulation of the questions also considers the characteristic of troublesome knowledge and threshold concept so that the instrument can be useful to obtain information about preservice teachers' conception which can be further analysed to reveal the troublesome knowledge and threshold concept. The validation process involved five experts in chemistry and chemistry education. Suggestions obtained from the validators were the revision of the sentence and additional explanation about the phenomena for item A and revision of the picture for items B and D. According to this validation process, there was no rejected item. The trial test was also conducted before the data collection process. This trial test aims to determine whether the instruments and the data collection technique are sufficient to gather the expected data.

The final version of the POE-MMDT still consists of four questions in the form of limited descriptions containing questions to explore students' mental models of chemical equilibrium topics. In these four questions, there are stages of prediction, observation, and explanation related to the phenomena of equilibrium $N_2O_4(g) \rightleftharpoons 2NO_2(g)$, as shown in Figure 1. The first question is about the equilibrium constant. The second and third questions concern the presence of reactants and products, equilibrium reactions can be started from any side, and concentration calculations at equilibrium. Meanwhile, the fourth question concerns the dynamic nature of the equilibrium reaction.

Phenomena:
This phenomenon shows the experiment which involved N_2O_4 gas (colorless) and NO_2 gas (brown)



Container tube filled with N_2O_4 gas　　Container tube filled with NO_2 gas

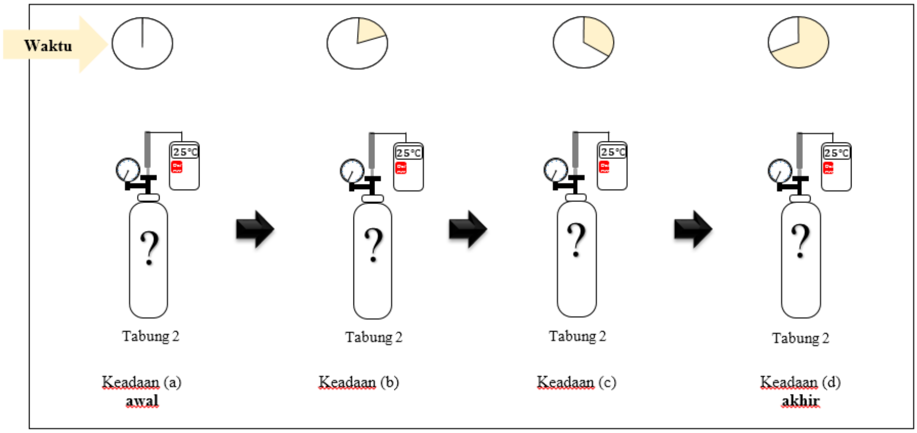
At 25°C, N_2O_4 is decomposed into NO_2 based on this following chemical reaction:

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

Figure 1. The phenomena of decomposition of $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

Some questions explored PSTs' initial understanding of a phenomenon at the prediction stage as shown in Figure 2. The PSTs were required to predict the colour and the needle's position in the manometer representing the gas pressure. These two parameters were used to explain the gas concentration changes during the process from the initial state to the equilibrium state. Then at the observation stage, there were pictures which have to be observed and questions to confirm the PSTs' initial understanding based on the results of their observations. In the final stage, namely explanation, PSTs' understanding was explored more deeply through questions regarding the results of their observations at the observation stage. This POE-MMDT consists of questions revealing PSTs' ability to explain concepts at the macroscopic, submicroscopic and symbolic levels. For example, some questions ask the PST to identify the species in each condition and correlate their answer with their observation regarding the colour change and pressure change. Some questions also ask the PST to express their explanation using the symbols in the form of chemical equations, quotients, and equilibrium constant equations, as well as the depiction of particles inside the tube. Thus, the information gathered from these three stages in POE-MMDT has the potential to show the PSTs' mental model of the chemical equilibrium concept.

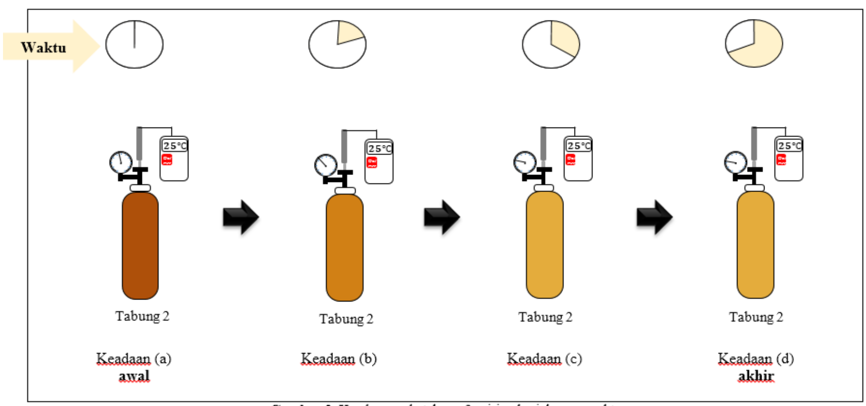
Predict: (Figure A)



If we have 0.2 mol NO_2 gas inserted into container UC 2, predict what will be observed in tube 2 and how is the needle position in the manometer at condition a, b, c, and d as presented in Figure A.

Observe: (Figure B)

The following picture shows the state of Tube 2 after being allowed to pass the time. Observe the **change in gas colour and pressure** in each state.



Gambar 2. Keadaan pada tabung 2 seiring berjalannya waktu

Based on your observations in Figure B, how are the changes observed in UC 2 during conditions (a), (b), (c), and (d)? Give explanation.

Figure 2 . Example of the question for the predict and observe stage

Data Analysis

The data obtained from the test results were analysed in four stages: the distribution of student answers according to the level of understanding, conceptual analysis, troublesome knowledge and threshold concept.

PSTs' response distribution to the comprehension level

PSTs' responses obtained in this study were distributed first to the level of understanding. The type of mental model used follows Supasorn's (2015) research, namely Sound Understanding (SU), Partial Understanding (PU), Partial Understanding with Specific Misunderstanding (PMU), Specific Misunderstanding (SM), and No Understanding (NU). Table 2 provides an example of the distribution of PSTs' responses into comprehension level categorisation.

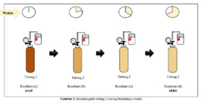
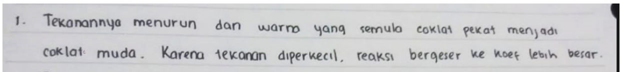
Table 2. The profile of comprehension level of Year 1 PST

Comprehension level	Percentage	Description
No response	11.10	PST did not provide any answer or only rewrite the test item.
No understanding	72.10	PST could not identify the reactant and the product or only recognized their existence without knowing the reason.
Partial understanding	16.67	PST could not explain the existence of the reactant and product correctly. Their explanation is partially correct
Sound understanding	0	PST provides a correct and comprehensive explanation of the existence of reactants and products.

Conceptual analysis

At this stage, conceptual analysis was carried out for each level of understanding. Conception analysis was done by comparing PSTs' answers with scientific concepts. The result of this analysis provides information about PSTs' conceptions that are in accordance with scientific concepts and also PSTs' misconceptions which are the understanding of PSTs that are not in accordance with scientific concepts. Table 3 shows an example of Year 1 PST's response at the observation stage. Since the response is not in accordance with scientific concepts, this response is categorised as a misconception.

Table 3. The example of Year 1 PST's response at the observation stage with misconception in equilibrium reaction

Students' responses	Translation
 According to your observation in Figure 2, how is the change observed from Tube 2 at conditions (a), (b), (c), and (d)? Explain the reason!  1. Tekanannya menurun dan warna yang semula coklat pekat menjadi coklat muda. Karena tekanan diperkecil, reaksi bergeser ke koef lebih besar.	The pressure is decreased, and the color, initially dark brown, is turned into light brown. This is due to the decrease of the pressure, which shifts the reaction to the side with a bigger coefficient.

Troublesome knowledge analysis

Troublesome knowledge analysis on chemical equilibrium is carried out in two stages. The first stage is identifying difficult concepts by comparing PSTs' answers with complete and incomplete understanding. Concepts that were considered difficult are the concepts owned by participants with complete understanding but not owned by participants with incomplete understanding. These concepts are defined as problematic knowledge. In the next stage, the troublesome knowledge obtained in the first stage is then categorised into troublesome knowledge according to Perkins (1999): Ritual Knowledge, Inert Knowledge, Conceptually Difficult Knowledge, Alien Knowledge, Tacit Knowledge and Troublesome Language as shown in Table 4.

Table 4. The example of analysis result of troublesome knowledge

The candidate of troublesome knowledge	Characteristic	The type of troublesome knowledge
The concentration of reactant and product in equilibrium state	Abstract: involved submicroscopic understanding Complex: involve the ability to draw a graph Terminology: Some terminologies are used in daily life with different meanings.	Conceptually difficult Troublesome language
Reactions occur in an equilibrium state	Alien and abstract	Alien and conceptually difficult
The equation of chemical equilibrium	Alien and abstract	Alien and conceptually difficult
Reaction rate at equilibrium state	Abstract and complex: involved the skill in drawing and interpreting the graph	Conceptually difficult

Threshold concept analysis

The threshold concept on the chemical equilibrium topic was analysed based on the student's understanding profile in line with the research of Park and Light (2009). The characteristics of minimum threshold concept have transformative, integrative, and troublesome characteristics (Davies, 2003; Hill, 2019). Therefore, the concept obtained from the results of the troublesome knowledge analysis has the potential as a threshold concept. The threshold concept candidates obtained from the troublesome knowledge analysis were reselected to meet the two characteristics of the other threshold concepts, namely transformative and integrative. Transformative characteristics were identified by comparing scientific concepts and the conceptions of one student with the highest understanding and two students with the lowest understanding, as shown in Table 5. Furthermore, concepts with transformative and troublesome characteristics were further analysed to determine whether or not the threshold concept had integrative characteristics, as shown in Table 6.

Table 5. The analysis of transformative characteristics of concepts in equilibrium constant

Concept label	Target concept	Conception		
		Student 1	Student 2	Student 3
The concentration of reactant and product in an equilibrium state	The concentration ratio between the reactant and product in the equilibrium state corresponds to the K value.	Misconception	Misconception	Sound understanding
Relationship between Q and K value	The value of Q is constant and the same as the K value	Sound understanding	No response	No response
	When Q is different from K, then the system will proceed to the equilibrium state from product to reactant (Q>K) or from reactant to product (Q<K)	Sound understanding	Sound understanding	No response
The calculation of reactant and product concentration at the equilibrium state	The value of the equilibrium constant can solve the calculation of reactant and product concentration at the equilibrium state.	Partial understanding	Partial understanding	No response
	The equilibrium constant of a system remains constant in the constant temperature	Sound understanding	Sound understanding	No response

Table 6. The determination of threshold concept

Concept found	Transformative	Integrative	Troublesome	Note
• Dynamic properties of an equilibrium reaction	√	√	√	Threshold concept
• Equilibrium constant	√	√	√	Threshold concept

In order to ensure the rigor and trustworthiness of the findings, data analysis was conducted to meet the dependability criteria. It was conducted through data coding to categorize the concepts and characteristics of troublesome knowledge. In this case, the authors measured coding accuracy and inter-coders' reliability. Besides, triangulation and consultation of data interpretation result to the literature to confirm and compare with the result of the previous study were conducted to meet the criteria of confirmability.

RESULTS

PSTs' Conception in Chemical Equilibrium Topic

The PSTs' conceptions in explaining chemical equilibrium were analysed through the MMDT-POE. Each response is compared with a validated answer to be further categorised into four levels of understanding: understand, partially understand, do not understand and no response. The results showed that none of the students fully understood the concept of chemical equilibrium. Most of the PST Years 3 and 4 poses an understanding of chemical equilibrium at the partial level. However, PST Years 1 to 4 also do not understand and experience misconceptions. The misconceptions experienced by students are shown in Table 7. Misconceptions were identified based on PSTs' consistent wrong answers when answering the concept.

Table 7. PSTs' misconceptions

No.	Misconceptions
1.	Equilibrium reactions are the same as irreversible reactions.
2.	The concentrations of the reactants and products at an equilibrium state are the same.
3.	The greater gas concentration at an equilibrium state depends on the gas that was first inserted into the container.
4.	The ratio of concentrations at an equilibrium state is in accordance with the ratio of the coefficients in the reaction equation.
5.	The gas that becomes the reactant depends on the gas that fills the container first.

Troublesome Knowledge in Chemical Equilibrium Topic

Troublesome knowledge analysis is carried out based on the PSTs' conceptions found. In line with Park and Light (2009), troublesome knowledge can be identified by comparing PSTs' conceptions with complete and incomplete understanding. In this study, no PST had a complete understanding as for the PST who understood in explaining the equilibrium constant but partially understood other sub-topics. Therefore, the first step to identifying troublesome knowledge is directly comparing PSTs' conceptions with scientific concepts. The presentation of the percentage of difficulties experienced by PST on concepts that have the potential to troublesome knowledge is shown in Table 8.

Table 8. Concept percentages in chemical equilibrium based on PSTs' difficulties

Concepts	Misconceptions or difficulties	Percentage
1. Presence of reactants and products at an equilibrium state	• PST do not have a conception that the concentrations of reactants and products at an equilibrium state are constant.	4.48
2. Concentration of reactants and products at equilibrium which can be achieved from any side	• PST do not have a conception of the ratio of concentrations of reactants and products at an equilibrium state. • The misconception that the concentrations of reactants and products at equilibrium are the same. • The misconception is that the ratio of gas concentrations at equilibrium equals the coefficients in the chemical reaction. • The misconception that the greater gas concentration at equilibrium depends on the first gas which fills the container. • The misconception that the concentrations of reactants and products at the equilibrium state are partially fixed and partially changed.	68.65
3. Changes in the concentration of reactants and products to an equilibrium state starting from any side	• PSTs have a misconception that an equilibrium state is reached when the concentrations of the reactants and products are the same. • PSTs have a misconception that the concentrations of reactants and products are partially fixed and partially changed when they reach equilibrium.	14.93
4. The equation for equilibrium reaction	• PSTs do not understand that the chemical equation shows the ratio of the decomposed reactants and the products formed.	64.18
	• PSTs have the misconception that the reactants in an equilibrium reaction depend on the first substance that fills the container.	49.25
5. Changes in the rate of reaction to an equilibrium state	• PSTs cannot explain the reaction rate when it reaches an equilibrium state.	91.00

(Continue on next page)

Table 8 (continued)

Concepts	Misconceptions or difficulties	Percentage
6. Concentration of reactants and products at an equilibrium state	• PSTs have a misconception that the concentrations of reactants and products are the same at an equilibrium state.	23.88
7. Reaction at an equilibrium state	• PSTs believe that an equilibrium reaction is the same as an irreversible reaction.	44.77
	• PSTs do not have a conception of reactions that occur at an equilibrium state.	
8. Rate of reaction at an equilibrium state	• PSTs do not conceive the reaction rate at an equilibrium state.	86.56
9. Relationship between Q and K values	• PSTs do not conceive of the relationship between Q and K at an equilibrium state.	92.54
	• PSTs do not have a conception of the relationship between Q and K in predicting the direction of the equilibrium reaction.	95.52
10. Calculation of concentrations of reactants and products at equilibrium	• PSTs do not have the conception that the value of the equilibrium constant remains the same for the same system at a constant temperature.	82.09
	• PSTs cannot calculate the concentrations of reactants and products at an equilibrium state.	100

Based on the data in Table 8, eight concepts were obtained as candidates for troublesome knowledge. Furthermore, an analysis of the characteristics was carried out to those eight concepts and adjusted to the type of troublesome knowledge, as presented in Table 9.

Table 9. Troublesome knowledge of chemical equilibrium concept

Troublesome knowledge candidates	Characteristics	Troublesome knowledge type
1. The concentration of reactants and products at equilibrium	• Abstract: Involve the understanding of the sub-microscopic level • Complex: Involve the ability to draw graphic • Different meanings of terms: Involve the terms from daily life.	Conceptually difficult and Troublesome language
2. Changes in the concentration of reactants and products towards equilibrium when starting from either side	• Abstract: involves understanding at the submicroscopic level • Complex: involves the ability to draw graphics	Conceptually difficult
3. The reaction that occurs at an equilibrium state	• Alien and abstract	Alien and conceptually difficult
4. Equilibrium reaction equation	• Alien and abstract	Alien and conceptually difficult
5. The rate of reaction at an equilibrium state	• Abstract and complex: involves the ability to draw/translate the graph	Conceptually difficult

(Continue on next page)

Table 9 (continued)

Troublesome knowledge candidates	Characteristics	Troublesome knowledge type
6. Rate reaction changes to reach a state of equilibrium	• Abstract and complex: involves the ability to draw/translate the graph	Conceptually difficult
7. Q and K value relation	• Complex and alien: involves mathematical calculations	Conceptually difficult
8. Calculation of concentrations of reactants and products at an equilibrium state	• Complex: involved mathematical calculations	Conceptually difficult

PSTs' Threshold Concept in Chemical Equilibrium

Based on the research of Park and Light (2009), the concept with troublesome characteristics has the potential as a threshold concept of chemical equilibrium. Therefore, further analysis was carried out on the eight Troublesome Knowledge shown in Table 9 to determine whether they also have the characteristics of the threshold concept. A concept is determined as a threshold concept if it has troublesome, transformative, and integrative characteristics (Hill, 2019). The analysis of determining the threshold concept can be seen in Table 10.

Table 10. Threshold concept determination

Found concept	Transformative	Integrative	Troublesome	Note
Dynamic characteristic of chemical equilibrium	√	√	√	Threshold concept
Equilibrium constant	√	√	√	Threshold concept

DISCUSSION

PSTs' Conception of Chemical Equilibrium and Its Troublesome Knowledge

The 67 PSTs provided various responses to POE-MMDT in each item number and stage of POE-MMDT. For example, in responding to Question number 2 (Shown in Figure2), some PSTs predict that the colour of Tube 2 in conditions a, b, c and d are all brown. While some PSTs have recognized that there will be some changes in colour and pressure. However, there were also various responses in providing the details of their explanation for their prediction. In the observation stage, the responses are similar, with only some differences in providing the details of their observation. The variety were also found in PSTs' responses to 12 sub-questions in the explanation stage. The variety of responses to POE-MMDT is due to the wide opportunity for the participants to express their thought, as has been explained by Sesen (2013). Besides, responding to the questions in the predict, observe and explain stages allows the PSTs to clarify and evaluate their understanding

(Lin et al., 2000). However, through a thorough analysis, this variety can be categorised into five categories of misconception, as shown in Table 7, which elaborates further into 19 difficulties in learning ten concepts covered in the chemical equilibrium topic, as shown in Table 8.

The equilibrium reaction concept is still challenging for students. It shows a similar finding from research conducted by Mensah and Morabe (2018) that stated the biggest challenge for students in understanding equilibrium reactions is determining how chemical reactions proceed to reach equilibrium state. When explaining the process towards a state of equilibrium, starting from the side of the reactants, products, or both, students do not have the conception that the chemical equation displays the ratio of the decomposed reactants and the formed products. PSTs who have this misconception are unable to explain that there are reactants and products in a state of equilibrium. This is evident when depicting particles in each state based on the observed colour and pressure changes. Furthermore, the PSTs are still deceived by the irreversible chemical equation. This is in agreement with the findings of Hackling and Garnett (1985), who unearthed that students' understanding of equilibrium reactions was heavily influenced by their prior knowledge of irreversible reactions. In an irreversible reaction, the reactant is the substance observed in the initial state. Then the substance will turn into a product in the final state. PSTs use the aforementioned notion for equilibrium reactions so that they do not grasp that equilibrium reactions can begin from any side and have the misconception that the reactants in an equilibrium reaction depend on the first inserted substance. As a result, the equilibrium constant will vary depending on the substance inserted. The equilibrium constant, however, will remain constant at the same temperature and system. As a result, the concept of a chemical equilibrium corresponds to conceptually difficult and alien knowledge.

To investigate PSTs' comprehension of the concept of reaction rate at equilibrium, they were required to explain why $^*N_2O_4$ was found over time while in the initial state there were only NO_2, $^*NO_2$, and N_2O_4, and the gas concentration remained constant. It turned out that most of the students could not explain the reason. The rate of reaction that occurs in an equilibrium state is abstract since the five senses cannot immediately perceive it. The results of these studies prove that translating graphs into reaction rates is challenging for students. Therefore, the two concepts regarding the reaction rate have a type of troublesome knowledge that is conceptually difficult.

The concept of the correlation between the equilibrium constant and the reaction quotient, as well as the calculation of reactant and product concentrations at equilibrium, have complex characteristics. Students are required to identify the value of the equilibrium constant, the equilibrium state's reaction quotient, and the equilibrium reaction's direction to investigate their understanding of these two concepts. It turns out that many students are still unable to distinguish between the two. Most students do not understand that in an equilibrium state, the concentrations of the reactants and products remain constant, allowing the value of the equilibrium constant to be obtained. Although students can calculate the value of K correctly, they do not understand that the value of Q at equilibrium is constant. It demonstrates that students are only focused on their calculations. Furthermore, when asked to explain the ratio of reactant and product concentrations, many students still rely on preexisting concepts such as reaction coefficients, even though the comparison can be seen from the value of K. Moreover, students have to perform rather complex mathematical calculations in order to calculate the reactant and product concentrations at equilibrium. This result agrees with Karpudewan et al. (2015), who found that students' ability to calculate equilibrium constants is severely limited.

The Threshold Concept of Chemical Equilibrium

Following the discovery of troublesome knowledge, a threshold concept analysis was carried out based on three characteristics: troublesome, transformative and integrative. Identifying the characteristics of a threshold concept requires more than a description of the new methods of thinking and practising that enable the concept. It also requires analysing the crucial cognitive elements that an individual needs to build and integrate to successfully develop the type of thinking that the threshold concept enables (Talanquer, 2015). If a concept creates a major change in understanding a certain concept, it is said to have transformative characteristics. Student 1 can correctly explain the concept of equilibrium reaction and reaction rate, however, students 2 and 3 cannot. Except for those two concepts, Student 2 can properly explain other concepts. If student 2 understands both concepts correctly, his understanding will be the same as student 1. Students successfully calculated the concentrations of reactants and products in an equilibrium state but were unable to determine the final result. It could be resulted by the fact that this concept requires fairly complex mathematical calculations. If student 1 can calculate the concentrations of reactants and products, his conception of the ratio of the concentrations of reactants and products will be correct so that his understanding becomes intact. Therefore, the concept of an equilibrium reaction and its reaction rate and mathematical calculations have transformative characteristics.

Understanding the threshold concept can integrate various concepts and ideas, allowing students to connect a topic with a broader field of study in order to solve problems. The concept of calculating reactants and products is connected to the concept of comparing reactant and product concentrations at equilibrium. This comparison is regarding the equilibrium constant's value. A student was found to be unable to calculate the concentrations of reactants and products, resulting in the student's misconception about the ratio of reactant and product concentrations at equilibrium. Similar to the concept of dynamic properties, this concept is also closely related to other materials, such as the ionisation constants of weak acids and weak bases, the calculation of the pH of buffer solutions, the calculation of the pH of salt hydrolysis, and the solubility equilibrium constant. Therefore, the concepts of dynamic properties and equilibrium constants have three characteristics from the threshold concept: troublesome, transformative, and integrative.

CONCLUSION

Based on the overall conception, PSTs majorly have a partial understanding of the concept of chemical equilibrium. PST Years 3 and 4 have the highest percentage of partial understanding, whereas PST Year 1 have the largest percentage of not understanding.

The misconceptions experienced by PSTs are that the equilibrium reaction is equivalent to an irreversible reaction. It includes the same concentrations of reactants and products at equilibrium, the higher gas concentration in the equilibrium state in accordance with the first present gas, the corresponding concentration ratio at the equilibrium state to the ratio of the coefficients in the reaction equation, and the depending gas on the gas that is first inserted. In addition to misconceptions, there are troublesome knowledge and threshold concept that teachers need to understand. All the troublesome knowledge found is conceptually difficult because students have difficulty connecting one concept with another. Meanwhile, the threshold concept found is the dynamic nature of the equilibrium reaction and the equilibrium constant by fulfilling the troublesome, transformative, and integrative characteristics.

IMPLICATIONS

The findings of this research show that PSTs have a limited understanding of chemical equilibrium. These findings are confirmed by this research and have been reported by previous studies from various countries. Therefore, it is needed to develop a learning strategy that can construct PTSs' conception. Information about troublesome knowledge and threshold concept is useful to determine the content coverage, sequence, and emphasis of the learning strategy and the curriculum of chemistry Teacher Education institutions.

LIMITATIONS

This research only used POE-MMDT to collect data from Preservice Teachers without any interview to confirm their explanation. Besides, data collection was conducted online due to COVID-19 pandemic, so the data collected might be limited to the response accessible via digital media such as Zoom and Google Classroom.

RECOMMENDATION

The result of this study can be a basis for developing curriculum and teaching and learning strategies to develop chemistry pre-service teachers' content knowledge. Besides, this research was conducted in a cross-section method which involves pre-service teachers from four different batches. A longitudinal study should be recommended to gather information on the development of pre-service teachers' conception and evaluate the strategy to anticipate the troublesome knowledge and threshold concept.

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