Conceptions and troublesome knowledge on acid-base using the two-tier multiple-choice diagnostic test

S Ardianti*, W Wiji, and T Widhiyanti
Departemen Pendidikan Kimia, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi No. 229, Bandung 40154, Indonesia

*septi.ardianti@upi.edu

Abstract. Acid-base is one of the materials that tend to be difficult for students to understand. Acid-base is a material that is conceptually solid and requires an integrated understanding of many of the concepts of introductory chemistry. This research is descriptive research that aims to find conceptions of students on acid-base subjects and asking about concepts that are considered troublesome according to their learning experiences. The subjects of this research were 31 students of class XI IPA 4 at SMAN 3 Pariaman. The instruments in this research are diagnostic tests and interviews. The result of this research is the students of SMAN 3 Pariaman have difficulties in learning about the acid-base subject with high category. The percentage of conceptions experienced by students in each indicator is 56.3% of students understand the concept, 20.8% misconception, and 22.9% do not understand the concept. In the second indicator, 45.2% of students understood the concept, 18.3% had misconceptions and 36.5% did not understand the concept. In the 3rd indicator, 35.5% of students understood the concept, 31.2% had misconceptions and 33.3% did not understand the concept. In the 4th indicator, 21.9% of students understand the concept, 27.7% do not understand the concept and 50.3% do not understand the concept. Meanwhile, the acid-base theory, the calculation of \( pH \) or \( pOH \), and the relationship between the degree of acidity (\( pH \)) and the degree of ionization (\( \alpha \)), and the acid equilibrium constant (\( Ka \)) or the base equilibrium constant (\( Kb \)) are considered troublesome knowledge because they can be conceptually difficult.

1. Introduction
Acid-base material is one material that tends to be difficult for students to understand. Sheppard revealed that the topic of acid-base is a conceptually dense topic and requires an integrated understanding of many introductory chemistry concepts such as the characteristics of particles in matter, the nature, and composition of solutions, atomic structure, ionic and covalent bonds, symbols, formulas, and reaction equations, ionization and balance [1]. The concept of acid-base is also used to understand more complex chemical concepts, such as organic chemistry and inorganic chemistry [2, 3]. The concepts studied in acid and base are not only limited to concepts that can be observed but also it must be learned as abstract concepts, namely concepts that cannot be sensed directly by humans [4]. To understand chemical concepts, including the concept of acid-base correctly, deeply, and comprehensively, one must understand multiple representations correctly [5]. A person's understanding of chemistry, especially the concept of acid and base is determined by his ability to understand, transfer, and related phenomena in multiple representations [6].

Understanding the concept is very important in learning chemistry. Students are said to have a complete understanding of chemical concepts if they can connect the three levels of representation, namely the macroscopic, submicroscopic, and symbolic levels. The ability of students to understand and
link the three levels of chemical representation reflects the mental model that students have [7]. Conceptual understanding in chemistry involves the ability to represent and translate chemical problems into macroscopic, microscopic, and symbolic representations. The presentation of chemical concepts with three levels of representation simultaneously is an important aspect that teachers need to pay attention to in the chemistry learning process [8].

The difference between concepts and conceptions is that the concept tends to an explanation that is generally considered correct, while the conception is more of an individual understanding which may not be following the understanding of experts [9]. Conception leads to a result of one's understanding based on the interaction of sources of knowledge, ideas, and cognitive activities when a person is faced with a problem. In short, it can be understood that a conception is a person's interpretation of a particular concept, therefore a person's conception can be different from one another [10].

Conception is a person's interpretation of a concept. Each student may have a different conception, depending on how each student interprets the concept received. Students' conceptions are formed based on their interactions with the environment. Students develop their conceptions through different sources such as personal experience (e.g., observation), gender, peer interaction, media, language, symbolic representations, textbooks, laboratory work, and so on [11]. Marlis classifies conceptions into three categories, namely conceptions that are following scientific concepts, conceptions that are different from scientific concepts (misconceptions), and conceptions that do not know the basis for taking them (only guessing/don't understand the concept) [12].

When understanding a concept at three levels of chemical representation, some things become difficulties or obstacles so that students are not able to understand chemical concepts as a whole [13]. Mayer & Land introduced the term troublesome knowledge as knowledge that is conceptually difficult or problematic for students so that it becomes an obstacle for students to learn [14]. There are 6 characteristics of troublesome knowledge, namely ritual knowledge, inert knowledge, conceptually difficult knowledge, alien knowledge, tacit knowledge, and troublesome language [14].

Ritual knowledge, where students can perform superficial tasks and techniques to get results but fail to understand the complexities that lie behind them. Inert knowledge, which is a concept that is difficult for students to understand due to the wrong influence of everyday experience and the strangeness and complexity of the scientist's view of a problem. Conceptually difficult knowledge, i.e., concepts are understood but not actively used or connected to the real world, seeing the big picture or making connections with everyday life. Alien knowledge, namely knowledge comes from views that are contrary to what students believe. Tacit knowledge, namely difficulties that come from the complexity of knowledge, inconsistency, or paradoxical nature. Troublesome language, namely difficulties caused by the use of special terms and have different meanings from the meaning in everyday life [14].

Conception and troublesome knowledge are related to each other. Analysis of conception and troublesome knowledge can be a guide for teachers in implementing appropriate learning strategies so that students can understand chemical concepts well and have a complete mental model.

2. Method

The research method used is the descriptive research method. This research was conducted in one of the high school schools in Pariaman city. The sample of this study amounted to 31 students consisting of 10 male students and 21 female students. Determination of the sample using purposive sampling, namely students who have done learning related to acid-base material. In this study, conceptual analysis was carried out using a two-tier mental model diagnostic test on acid-base titration material. Troublesome knowledge was identified based on the analysis of conception findings and student responses through semi-structured interviews about concepts that were considered troublesome. The instrument used in this study is valid and reliable. The validity of this instrument has been tested by lecturers and teachers and has been declared valid. While the reliability value for the objective test is 0.91 with a very high category. The percentage value of students who understand concepts, misconceptions, and do not understand concepts uses the equation proposed by Sudijono [15].
3. Result and Discussion

3.1. Conceptions on acid-base

The research data was obtained from the results of a two-tier multiple-choice diagnostic test given to 31 students in class XI IPA 4 at SMAN 3 Pariaman. To identify students' conceptions, the answers given by students are categorized into four categories, as shown in Table 1 [16].

| Student Answer Type | Explanation | Category |
|---------------------|-------------|----------|
| T-T (True-True)     | Correctly answer both levels of questions | Understand |
| T-F (True-False)    | Answered correctly on the first level and answered incorrectly on the second level | Misconception |
| F-T (False-True)    | Answering wrong on the first level and right on the second level | Misconception |
| F-F (False-False)   | Answer with one of the two levels of questions | Do not understand |

Acid-base material consists of 4 learning indicators. To determine the level of student understanding, 20 questions that represent 4 learning indicators are given. Students' diagnostic test results are categorized into 3 groups, namely: 1) students who understand; 2) students who have misconceptions; and 3) students who do not understand the concept. Data on the results of understanding the conceptions of class XI IPA 4 SMAN 3 Pariaman students can be seen in Table 2 and Figure 1 below.

Table 2. The results of the analysis of students' conceptions on indicators of acid-base learning

| No | Indicator | Category Answers Per-Indicator |
|----|-----------|-------------------------------|
| 1  | 1         | Understand: 56.3 %             |
|    |           | Misconception: 20.8 %          |
|    |           | Do not understand: 22.9 %      |
| 2  | 2         | Understand: 45.2 %             |
|    |           | Misconception: 18.3 %          |
|    |           | Do not understand: 36.5 %      |
| 3  | 3         | Understand: 35.5 %             |
|    |           | Misconception: 31.2 %          |
|    |           | Do not understand: 33.3 %      |
| 4  | 4         | Understand: 21.9 %             |
|    |           | Misconception: 27.7 %          |
|    |           | Do not understand: 50.3 %      |
| Average & | | Understand: 42.9 %             |
|   | | Misconception: 23.7 %          |
|   | | Do not understand: 33.4 %      |

Information

1st indicator: Analyzing the properties of solutions based on the acid-base theory according to Arrhenius, Bronsted-Lowry, and Lewis

2nd indicator: Analyzing the properties of acid-base solutions using litmus paper and indicators

3rd indicator: Calculate the pH or pOH of an acid or base solution of known concentration

4th indicator: It relates the degree of acidity (pH) with the degree of ionization (α), and the acid equilibrium constant (Ka) or the basic equilibrium constant (Kb).

Figure 1. Students answer category

Based on Table 2 and Figure 1, it can be seen that students' understanding of the concept of acid-base material is still low. The student's understanding of concepts was the lowest in the 4th indicator [connecting the degree of acidity (pH) with the degree of ionization (α), and the acid equilibrium constant (Ka) or base equilibrium constant (Kb)] in the high category. The second order is found in the
3rd indicator [calculate the pH or pOH of an acid or base solution of known concentration] with a high category. The third order is found in the 2nd indicator analyzing the nature of acid-base solutions using litmus paper and indicators] with a fairly high category. And the last one is in the 1st indicator analyzing the properties of the solution based on the acid-base theory according to Arrhenius, Bronsted-Lowry, and Lewis] with a fairly high category.

3.1.1 Indicator 1: Analyzing the Properties of Solutions Based on Acid-Base Theory According to Arrhenius, Bronsted-Lowry and Lewis.

The misconceptions experienced by students in this learning indicator are caused because students experience inverted concepts between the Arrhenius acid-base theory, Bronsted-Lowry acid-base, and Lewis acid-base theory. Students also have difficulty in distinguishing acid and base compounds from each of the theories above. In the Arrhenius acid-base problem, students assume that \( \text{NH}_3 \) is an Arrhenius acid because there is an H atom in its molecular formula. However, students do not understand that Arrhenius acid is a substance in the aqueous solution that will increase the concentration of the hydronium ion, \( H_3O^+ \).

Students assume that according to the Bronsted-Lowry acid, it accepts protons, while bases donate protons. In the reaction between \( HCO_3^- \) and \( H_2O \), students think that the \( HCO_3^- \) ion acts as a Bronsted-Lowry acid because it accepts a proton, while \( HCO_3^- \) acts as a base because it donates a proton. This misconception is following the results of research which states that Bronsted-Lowry acids are proton acceptors, while Bronsted-Lowry bases are proton donors [17]. This misconception may be caused by students memorizing concepts, so it can lead to misconceptions.

Whereas in Lewis acid-base theory, students have difficulty in determining substances that act as electron-pair acceptors (acceptors) and substances that act as electron-pair donors (donors). Sometimes students are not careful in answering questions so that several observable correct answers are missed and students have difficulty in determining acid and base compounds in a reaction equation.

3.1.2 Indicator 2: Analyzing the Properties of Acid-Base Solutions Using Litmus Paper and Indicators.

The difficulty experienced by students in this learning indicator is because students have difficulty in determining the color of litmus paper when dipped in an acid-base indicator. Students do not know about the color changes that occur on the litmus paper, where the color of litmus in an acidic solution is red and an alkaline one is blue. Students also have difficulty in answering questions related to natural indicators. Some students think that all types of plants can be used as natural indicators. While the types of plants that can be used as natural indicators are plants that have dyes where the color is different in an acidic environment and an alkaline environment.

3.1.3 Indicator 3: Calculating the pH or pOH of an Acid or Base of Known Concentration

The difficulties experienced by students in learning indicators are caused because students do not know the pH range in acidic and alkaline conditions. This is also because students have difficulty in changing pH into concentration, in other words, students have difficulty in determining the results of the logarithmic equation. The difficulty in determining the pH and pOH values of a solution whose concentration and valence are known is because students do not know the formula used in the calculation or an error occurs when doing the calculation.

3.1.4 Indicator 4: Correlation Degree of Acidity (pH) with Degree of Ionization (\( \alpha \)), and Acid Equilibrium Constant (\( K_a \)) Or Base Equilibrium Constant (\( K_b \)).

In this indicator question, students assume that the greater the concentration of acid and base, the greater the strength of the acid and base. This misconception is the same as the results of research which states that more concentrated acids and bases have greater acid and alkaline strength [18,19,20], whereas in other studies it is stated that the strength of the acid increases if the concentration of \( H^+ \) ions from the ionization results also increases. Students also assume that the smaller the concentration of acid, the greater the strength of the acid because the pH is getting bigger [17,21]. This misconception is the same
as research which states that strong acids always have a higher pH than weak acids [22]. This is because students memorize strong acids/bases and weak acids/bases, without paying attention to the submicroscopic description or the values of \( K_a \) and \( K_b \) that have been given to the problem. This memorization can cause students to experience misconceptions about acid-base material.

Acid-base misconceptions that many students experience when viewed from multiple representations occur in questions that involve submicroscopic images. This is because students do not pay close attention to the submicroscopic description of the problem, students are more involved in their understanding by rote. According to (Romine et al. 2016), students who understand concepts, rules, and principles by rote, will cause a lot of misconceptions [23]. In addition, students in understanding concepts use a simplification of concepts, not using understanding multiple representations, especially submicroscopic, so that students experience many misconceptions. Simplification of the material can lead to misconceptions [24, 25]. According to (Sunyono 2015), a person's understanding of chemistry is determined by his ability to transfer and connect phenomena in chemical representations [6]. If the ability regarding multiple representations and the relationship between the three levels of representation is low, it will most likely lead to misconceptions [5,26]. Submicroscopic representation is important to study because submicroscopic representation is the only representation that can describe the particle nature of matter which is the basis for the interpretation of understanding or chemical phenomena [26]. Submicroscopic representation is very important to understand and explain chemical phenomena [19]. So, multiple representations and the relationship between representations must be studied properly and must be used in understanding chemical concepts to have a complete and correct understanding of chemical concepts.

3.2 Troublesome knowledge on acid-base

The troublesome knowledge of acid-base was identified from the analysis of the findings of deep conceptions and students' responses about difficult or troublesome concepts about acid-base according to their learning experiences. Students' statements about acid-base troublesome knowledge according to their learning experiences are shown in Table 3. Acid-base theory, calculation of pH or pOH, and the relationship between the degree of acidity (\( pH \)) and the degree of ionization (\( \alpha \)), and the acid equilibrium constant (\( K_a \)) or the base equilibrium constant. (\( K_b \)) is considered inconvenient because it can be conceptually difficult. This is related to the findings of the conception.

| Troublesome concept                        | Example of prospective student statement                                                                 | Type of troublesome knowledge |
|--------------------------------------------|-----------------------------------------------------------------------------------------------------------|------------------------------|
| Arrhenius, Bronsted-Lowry, and Lewis acid-base theory | "It's hard for me to imagine something abstract and connect what I see in real life on a molecular level."  
"I don't know what a proton donor and an electron-pair donor are and what the difference is, and vice versa."  
"The concept that I understand is the reverse between the Arrhenius, Bronsted-Lowry, and Lewis acid-base theories".  
"I don't understand how to determine the Lewis structure and electron pairs". | Conceptually difficult |
| Calculation of pH or pOH                   | "I don't know the formula for determining pH".  
Logarithms are a difficult subject for me.  
"I'm confused in determining which is an acid and a base compound, so I don't know whether I should determine the pH first or the pOH".  
"I don't understand what concentration means, is it moles or molars." | Conceptually difficult |
| The relationship between the degree of      | "In my opinion, the greater the concentration of acid and base, the greater the strength of the acid and base." | Conceptually difficult |
Troublesome concept | Example of prospective student statement | Type of troublesome knowledge
--- | --- | ---
Acidity (pH) and the degree of ionization (α), and the acid equilibrium constant (Ka) or the basic equilibrium constant (Kb) | "I understand that the lower the concentration of the acid, the greater the strength of the acid because the higher the pH." | |
"I don't understand what is meant by the degree of ionization (α), and the acid or base equilibrium constant (Ka/Kb)". | |

Based on Table 3. Arrhenius, Bronsted-Lowry, and Lewis acid-base theory; calculation of pH or pOH; and the relationship between the degree of acidity (pH) and the degree of ionization (α), and the acid equilibrium constant (Ka) or the alkaline equilibrium constant (Kb) is troublesome knowledge because they are conceptually difficult. The concept is abstract, complex, and involves mathematical calculations so that it can lead students to misconceptions. Park & Light suggested that the difficulty of knowledge can be caused by the complexity and level of abstraction of a concept [27]. Abstract concepts of acids and bases include the transfer of protons between acids and bases based on the Bronsted-Lowry concept of acids and bases, the ionization of $H^+$ ions or $OH^-$ ions in water based on the Arrhenius concept of acids and bases, and the transfer of lone pairs of electrons (PEB) based on the Lewis concept. The occurrence of these three events cannot be observed using the five senses.

Students assume that compounds containing $H$ atoms are acidic because they will be able to produce $H^+$ ions when dissolved in water. The correct concept is that three acid-base theories define acids and bases. Even though there are $H$ atoms, it does not necessarily mean that the compound will release $H^+$ ions, for example, NaOH compounds. The misconceptions experienced probably stem from the tendency of students to explain the nature of acids and bases with only one theory. Students assume that one acid-base theory can explain all acid-base reactions. Students assume that all compounds containing $H^+$ atoms are acids and those containing $OH^-$ groups are bases.

There are still misconceptions about the determination of acid strength because students do not understand that pH indicates the amount of $H^+$ ion concentration in solution and is different from the ability of a compound to ionize/dissociate in an aqueous solvent [28]. Similar to the misconceptions found in the determination of bases, this is possible because students do not understand that pOH indicates the amount of $OH^-$ ions in the solution [28], pH shows the large concentration of $H^+$ ions in the solution [28]. pH is different from the ability of a base to ionize/dissociate in water. Students do not understand that pH indicates the total concentration of $H^+$ ions in the solution and is different from the ability of a compound to ionize/dissociate in aqueous solvents [28].

4. Conclusion
The percentage of conceptions experienced by students in each indicator is 56.3% of students understand the concept, 20.8% misconception, and 22.9% do not understand the concept. In the second indicator, 45.2% of students understood the concept, 18.3% had misconceptions and 36.5% did not understand the concept. In the 3rd indicator, 35.5% of students understood the concept, 31.2% had misconceptions and 33.3% did not understand the concept. In the 4th indicator, 21.9% of students understand the concept, 27.7% do not understand the concept and 50.3% do not understand the concept. Meanwhile, the acid-base theory, the calculation of pH or pOH, and the relationship between the degree of acidity (pH) and the degree of ionization (α), and the acid equilibrium constant (Ka) or the base equilibrium constant (Kb) are considered troublesome knowledge because they can be conceptually difficult.

5. References
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Acknowledgments
Authors would like to thank the Departemen Pendidikan Kimia Universitas Pendidikan Indonesia and SMAN 3 Pariaman for their guidance and support in the implementation for this research.