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IDENTIFICATION OF STUDENTS' MISCONCEPTIONS ON ACID-BASE USING FOUR TIER DIAGNOSTIC TESTS

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Abstract - Students often have difficulty understanding acid-base material, so it has the potential to cause misconceptions. If the students' misconceptions are left unattended and not immediately identified, there will be ongoing misconceptions. This study aimed to describe the misconceptions that occur in acid-base material and determine the large percentage of students who experience misconceptions. The method used in this research is descriptive quantitative. The subjects of this study consisted of 108 students of class XII MA Matholi'ul Anwar. The identification of misconceptions used a four-tier diagnostic test instrument with 20 items. The students' answers from the test were then analyzed and categorized into understanding concepts, not understanding concepts, and misconceptions. This study found that 50% of students hold misconceptions about acid-base theories, 59% in acid-base indicators, 55% in acid-base ionization constant, 58% in pH, 55% in the calculation of pH and 51.9% in pH concepts in the environment.

Keywords: *misconception; four-tier diagnostic test; acid-base, ionization constant*

INTRODUCTION

Concepts in chemistry are tiered concepts that start from simple concepts to more complex concepts. Students' initial concepts become the basis for learning more complex concepts. Complex concepts can only be mastered correctly if the basic concepts have been mastered correctly (Izza et al., 2021). Students often have difficulty understanding chemistry material, so they interpret themselves according to their initial concepts. However, the interpretation results are sometimes not the same as scientific concepts, or it is called misconceptions (Syahyani, 2018).

Misconceptions often occur during the learning process. Therefore, an effort is needed to evaluate whether students master the concept correctly or not so that misconceptions do not occur continuously. Misconceptions have an impact on students' understanding of the next material. It is because the chemistry concepts are interrelated to form a concept hierarchy. Research in several countries shows that misconceptions are resistant. Misconceptions occur at the next level because students cannot connect between concepts. It affects an unbroken chain of misconceptions (Purtadi & Permana, 2012). Therefore, students' misconceptions are of particular concern among researchers because they can affect student learning outcomes (Islami et al., 2019).

One of the students' misconceptions about chemistry subjects is acid and base. Acid-base material is one of the important materials for class XI SMA/MA, which includes understanding concepts and multiple representations (Anggraeni et al., 2018). The acid-base material contains several prerequisite materials for students, including stoichiometry, the nature of matter and

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solutions, chemical reactions, and chemical equilibrium. These materials affect students' comprehension of acid-base materials.

On the other hand, acid-base is included in the prerequisite materials for subsequent materials, namely buffer solutions, salt hydrolysis, and acid-base titration (Artdej et al., 2010). Determining the acid-base mixture reaction and calculating the pH of an acid-base mixture requires a good comprehension of the difference or identification of acid-base compounds. In this case, the theory of acid-base and acid-base strength needs to be comprehended well. A good comprehension eases students to comprehend the acid-base titration, buffer solution, and salt hydrolysis concepts.

Diagnostic tests can identify students' misconceptions. Diagnostic tests are tests to discover the students' weaknesses so that teachers can do accurate treatment. The diagnostic test aims to find out the students' learning progress related to weaknesses in certain materials (Rusilowati, 2015). The complex acid-base material often causes misconceptions, so an evaluation is needed to determine the accuracy of students' comprehension after learning (Medina, 2015).

Each test aims to determine the students' disability. Multiple choice tests cannot be used to reveal students' misconceptions because this test only measures students' comprehension. It does not identify misconceptions. Two-tier and three-tier diagnostic tests are used to reveal students' misconceptions. However, the test lacks in revealing students' misconceptions (Peşman & Eryilmaz, 2010). Therefore, a more effective diagnostic test is needed to discover students' misconceptions (Qistih Fariyani et al., 2016).

The four-tier diagnostic test is a test with four tiers. The first tier is multiple choice, the second tier is student belief, the third tier is the reason, and the fourth tier is belief and reason from the third tier. The four-tier diagnostic test was chosen because this test can determine the difference in the confidence in the responses and beliefs of students' reasons level so that it can discover more about students' misconceptions (Gurel et al., 2015). The four-tier diagnostic test produces a more accurate and specific answer combination analysis. Thus, teachers can accurately classify students' conceptual comprehension, define concepts that require special emphasis, and design more effective learning so that students' misconceptions can be reduced (Rachmania Erika Putri 2021).

There is still limited research on identifying misconceptions about acid-base materials using four-tier diagnostic tests. Suharto pointed out that 4.13% of the 111 journals on identifying misconceptions in science used four-tier diagnostic tests. The diagnostic method with an open-ended question and multiple-choice tests is widely used, 23.97% and 32.23%, respectively. The rest used the interview method, two-tier, and three-tier diagnostic tests (Soeharto et al., 2019). Several previous misconceptions studies have also used two-tier and three-tier diagnostic tests (W. Anggraeni, 2017; Aytekin et al., 2018; Bayrak, 2013; Dewi et al., 2018; Mashfufatul Ilmah, 2017; Mubarokah et al., 2018; Nugroho et al., 2019; Rusmini et al., 2021; Siswaningsih et al., 2020).

Based on the interview results, one of the MA chemistry teachers in Lamongan said that the teachers did not recognize if students often experienced misconceptions during the chemistry learning process and acid-base material. The teachers also have never made a diagnostic test to reveal misconceptions. Therefore, research is needed to identify students' misconceptions using a four-tier diagnostic test on acid-base material.

METHOD

This research used the descriptive quantitative method. The subjects of this study were 108 students of class XII MIPA in one of the MA in Lamongan. The research instrument was 20 items of the four-tier diagnostic test. The steps for developing a four-tier diagnostic test included:

making a concept map, researching related literature, developing multiple choice questions with free responses, conducting interviews with students, validating content, and making continuous improvements. The content validation of the four-tier diagnostic test instrument was conducted by four validators (three lecturers and one chemistry teacher) to determine the validity. Then a trial was conducted to determine the validity, the reliability, the level of difficulty, and the discriminating power of the items.

The data sources were teachers and students. Data collection techniques used tests and interviews. The data analysis technique included (1) misconceptions analysis with the interpretation of the four-tier diagnostic test results to classify students into understanding concepts, not understanding concepts and misconceptions criteria. The interpretation guideline of diagnostic tests referred to Fariyani's research (Qisthi Fariyani et al., 2016).

Table 1. Interpretation of Four Tier Diagnostic Test Results

Response	Confidence Response	Reason	Confidence Reason	Criteria
Correct	High	Correct	High	Understand
Correct	Low	Correct	Low	Not understand
Correct	High	Correct	Low	Not understand
Correct	Low	Correct	High	Not understand
Correct	Low	Incorrect	Low	Not understand
Incorrect	Low	Correct	Low	Not understand
Incorrect	Low	Incorrect	Low	Not understand
Correct	High	Incorrect	Low	Not understand
Incorrect	Low	Correct	High	Not understand
Correct	Low	Incorrect	High	Misconception
Correct	High	Incorrect	High	Misconception
Incorrect	High	Correct	Low	Misconception
Incorrect	High	Correct	High	Misconception
Incorrect	High	Incorrect	Low	Misconception
Incorrect	Low	Incorrect	High	Misconception
Incorrect	High	Incorrect	High	Misconception

Score 1 for correct answer and score 0 for incorrect answer. The level of confidence was high if students chose the confident option, and the level of confidence was low if students chose the unconfident option. Furthermore, the percentage of students who understand the concept, do not understand the concept and misconceptions was calculated. (2) Analysis of interview results referred to Miles and Huberman, namely data reduction, data presentation, and drawing conclusions or verification.

RESULTS AND DISCUSSION

Students' Misconceptions of Acid-Base Materials

The students' comprehension level analysis results for each item (of the 20 items tested) are shown in Table 2 (Qisthi Fariyani et al., 2016).

Table 2. Percentage of Student Responses

Item	Number of Students		
	Understand Concept	Not understand the concept	Misconception
1	26.9%	27.8%	45.4%
2	31.5%	15.7%	52.8%
3	10.2%	28.7%	61.1%
4	22.2%	36.1%	41.7%
5	14.8%	33.3%	51.9%
6	20.4%	30.6%	49.1%
7	19.4%	30.6%	50.0%
8	19.4%	32.4%	48.1%
9	10.2%	33.3%	56.5%
10	5.6%	26.9%	67.6%
11	13.0%	38.9%	48.1%
12	14.8%	31.5%	53.7%
13	3.7%	40.7%	55.6%
14	9.3%	23.1%	67.6%
15	9.3%	40.7%	50.0%
16	4.6%	37.0%	58.3%
17	16.7%	34.3%	49.1%
18	11.1%	35.2%	53.7%
19	35.2%	13.0%	51.9%
20	22.2%	16.7%	61.1%
Average	16%	30%	54%

Table 2 showed that 108 students had misconceptions about all acid-base material concepts. The highest percentage of misconceptions (59%) was the acid-base indicator theory concept, and the lowest percentage (50%) was the acid-base theory concept.

The 6 of 20 of the four-tier diagnostic test items for each concept on acid-base material had the highest percentage of misconceptions. The whole concept of acid-base material had a percentage of >10%, so the further discussion was needed. If the students' misconceptions were >10%, then a more in-depth discussion was needed (Hadinugrahaningsih et al., 2018).

In the acid-base theory concept of item 3, students were asked to determine the conjugate acid and acid from the reaction of $CN^-(aq) + H_2O(l) \rightleftharpoons HCN(aq) + OH^-(aq)$. According to the reaction, HCN acts as a conjugate acid because it accepts a proton, while H2O acts as acid as the acid because it releases a proton. However, students experience some misconceptions, including:

1. HCN and H_2O are acidic because they release protons
2. H_2O is base because it accepts a proton from HCN
3. CN^- is base because it accepts a proton from H_2O
4. OH^- and CN^- are acidic because they accept protons

The interviews results between researchers and students who experienced misconceptions were as follows:

R : *Nomor 3 jawabannya apa?*
S : *H_2O dan OH^- Bu*
R : *Kenapa memilih itu? H_2O itu termasuk spesi apa?*
S : *H_2O sifatnya asam Bu karena menerima proton*
R : *Kamu tahu teori asam basa Bronsted Lowry tidak? Coba jelaskan*
S : *Asam itu senyawa yang memberikan pasangan elektron, kalau basa itu yang menerima pasangan elektronnya Bu.*

Description:
R = Researcher
S = Student

The results showed that students have difficulty determining conjugate acid-base pairs. Students realized that a Brownsted-Lowry base was a particle that had an H atom and negative charge. In addition, students also assumed that conjugate acid-base pairs had positively and negatively charged ions that can neutralize each other (Aytekin et al., 2018). It was proven by students who could not distinguish compounds that accept or release protons (Anjamputra et al., 2019).

Students' misconceptions occurred because they had difficulty distinguishing between Bronsted Lowry's theory of acid-base and Lewis's theory of acid-base. Students had difficulty understanding the Brownsted-Lowry acid-base concept because they only recognized the Arrhenius acid-base concept. Another study revealed that some students had misconceptions about all concepts (Mubarak & Yahdi, 2020). Therefore, most students had difficulty answering questions about acid-base theory (Fajrin et al., 2020).

Item 20 was the acid-base indicators concept. Students were asked to determine which solution was acidic. Acidic solutions were listed in numbers 2 and 3. The red litmus paper remained red in the solution in number 2, but the blue litmus paper turned red. However, students had some misconceptions, including:

1. Red litmus in alkaline solution turned red
2. Blue litmus in an acid solution turned blue
3. Blue litmus in alkaline solution turned red
4. Blue litmus in acid and the alkaline solution was blue

These results indicated that students' misconceptions were due to a lack of understanding of the questions. In addition, some students could not explain how litmus paper works, so they had difficulty determining the solution characteristics. The interviews results between researchers and students were as follows:

R : *Apa kamu paham soal nomor 20?*
S : *Paham Bu. Larutan yang bersifat asam itu larutan 2 dan 3*
R : *Coba dijelaskan.*
S : *Lakmus merah kalau dimasukkan dalam larutan basa warnanya akan tetap merah Bu.*

The results showed that students' misconceptions about the acid-base indicators concept were due to their low generalization ability. They only focused on memorizing theory without comprehending the basic concept (Harizal, 2012). Other researchers also stated that misconceptions were caused by the lack of students' ability to classify the acid-base solution properties. Students had difficulty understanding this concept (Buchori et al., 2013).

Based on the acid strength (pH), item 10 presented the pH data of KOH solutions with various concentrations and the same volume. Students were asked to rank the strength of the bases. The higher the pH value, the stronger the alkaline solution. However, students had some misconceptions, namely:

1. Dissociation degree of KOH = 1
2. The greater concentration, the strength of the base also increased
3. The lower the concentration of OH^- ions, the stronger the base
4. Volume did not affect pH

Several studies also stated a misconception in the acid strength (pH) concept with a percentage of >40%. It proved that many students had misconceptions. Misconceptions occurred because students did not understand if pH indicates the amount of H^+ ion concentration in a solution. Students also assumed that pH indicated the acid strength. If the pH were lower, the acid strength would also increase (Amry & Rahayu, 2017). The interviews results between researchers and students who experienced misconceptions were:

R : *KOH itu termasuk asam/basa?*
S : *Basa Bu.*
R : *Urutan kekuatan basanya bagaimana?*
S : *Urutannya* 5 > 4 > 3 > 2 > 1
R : *Kenapa kok bisa begitu?*
S : *Karena konsentrasinya bertambah Bu, sehingga kekuatan pHnya juga semakin kuat*
R : *Apakah volume juga mempengaruhi kekuatan basanya?*
S : *Tidak tahu Bu saya lupa.*

The cause of the misconception was that students did not know the definition of pH and acid-base solutions, which always contain H^+ and OH^- ions at certain concentrations (Buchori et al., 2013). In addition, students had difficulty connecting concepts. They recognized that the acid compound strength on the pH scale when the acid compound was on the right meant it was weak. While the alkaline compounds' strength on the pH scale was on the right, meaning that it was getting stronger.

Item 13 on the acid-base ionization constant concept (K_a/K_b), students were asked to determine the K_b value of a conjugate base. Students should recognize whether CHOOH was a strong or weak acid. After that, they applied the formula to find the K_b value with the correct concept. The correct K_b value was 5.56 x 10^{-11}. The calculation was as follows:

$$Kb = \frac{Kw}{Ka} = \frac{1{,}0 \times 10^{-14}}{1{,}8 \times 10^{-4}}$$

$$= 5{,}56 \times 10^{-11}$$

If the value of K_b was less than K_a, then the K_b value was greater than K_a. However, there were some student misconceptions, including:
1. The K_a value was smaller than K_w, then the K_b value was smaller than K_a
2. The K_b value was smaller than K_w, then the K_a value was smaller than K_b
3. The K_w value was greater than K_b, then the K_a value was smaller than K_b
4. The K_w value was greater than K_a, then the K_b value was greater than K_a

These results indicated that students could not distinguish the definition of K_a, K_b, and K_w. The interviews results between researchers and students who experienced misconceptions were as follows:

R : *Masih ingat jawaban nomor soal 13?*
S : *Masih Bu. Jawaban saya* 5,56 x 10^{-11}
R : *CHOOH itu termasuk asam kuat atau lemah sih?*
S : *Asam kuat Bu.*
R : *Kalau begitu apa perbedaan antara K_a, K_b,* dan *K_w?*
S : *Jika nilai K_b lebih kecil dari K_w, maka nilai K_a juga lebih kecil dari K_b*

Research showed that students had difficulty understanding the acid-base ionization constants concept. Students did not understand that if the K_b value was less than K_w, the K_a value was greater than K_b. The misconception was related to the lack of students' comprehension of the difference between the dissociation of strong acids and weak acids. Students only focused on memorizing the K_a calculation formula without understanding the basic concepts (Artdej et al., 2010).

Another study showed that students considered the ionization constant of an acid and the ionization degree of acid to be the same thing. It was because there was the word ionization in both. According to the correct theory, the ionization equilibrium constant for an acid differs from the degree of ionization. The equilibrium constant refers to the general measure of the equilibrium constant for the ratio relative to water. In contrast, the ionization degree refers to the ratio of moles of solute to the amount of solute (Utami et al., 2020).

In calculating the pH concept of the solution in item 14, students were asked to determine the concentration of a two-valent strong acid solution. It was known that the pH was 4-log 2. The calculation was as follows:

$$H^+ = [M] \text{ x valensi}$$

$$2 \text{ x } 10^{-4} = [M] \text{ x } 2$$

$$[M] = \frac{2 \text{ x } 10^{-4}}{2}$$

Students should calculate the concentration of a two-valent strong solution using the correct formula. The concentration of the strong acid solution was $10^{-4,}$ and the valence of the acid = 2. However, students had some misconceptions, including:

1. $[H^+] = 2 \text{ x } 10^{-4}$ M
2. $\alpha = 2$
3. Strong acids had a lower pH
4. The solution was an HCl solution

Research showed that students could not determine the acid or base solution and determine the number of H^+ ions in strong acids and OH^- ions in strong bases that are released. The pH calculation of the student's acid-base solution was wrong. The interviews results between researchers and students were:

R : *Nomor 14 pH nya berapa?*
S : *4-log 2 Bu*
R : *Berarti konsentrasi larutannya berapa?*
S : *2 x 10^{-4} Bu*
R : *Rumusnya bagaimana ingat ngga?*
S : *H^+ = [M] x valensi*
R : *Berarti valensi asamnya berapa?*
S : *Saya tidak tahu Bu.*

Another reason included students being unable to determine the nature and strength of an acid-base solution, so they incorrectly answered the calculation (Buchori et al., 2013). It was also supported by research that showed that students thought that the acid strength increases if the pH increases. Based on the explanation above, students determined the acid-base strength based on the pH value without understanding the dissociation concept (Aytekin et al., 2018; Siswaningsih et al., 2020).

Based on the pH concept in item 19, students were asked to determine whether wastewater was contaminated with alkaline. Bases have a pH > 7, so alkaline polluted wastewater has a pH > 7. Some misconceptions that occurred include:

1. Wastewater contaminated with alkaline has a pH < 7 because the nature of the base has a high pH
2. A base is a compound that accepts OH^- ions in water so that the carrier of basic nature is OH^- ions
3. Bases include compounds or ions that accept electron pairs because bases have lone pairs
4. The strength of the base is not affected by the number of OH^- ions produced by the basic compound in its solution, but the strength of the base is affected by the K_b value constant.

This misconception showed that students had difficulty connecting a concept with everyday life. Misconceptions occurred when they assumed that the pH value changes of river water did not affect water quality. Meanwhile, based on the correct theory, one of the main sources of water pollution comes from waste, which will change water quality (Nasution & Slamet, 2020). The interviews results between researchers and students were as follows:

R : *Masih ingat jawaban nomor 19?*
S : *Masih*
R : *Coba urutkan basa dari yang lemah sampai yang kuat?*
S : *Nomor 1, 4, 5*
R : *Kalau di skala pH semakin ke kiri semakin apa?*
S : *Semakin kuat Bu*
R : *Coba beri contoh, kalau dalam kehidupan sehari-hari pH dalam lingkungan berkaitan dengan apa?*
S : *Saya tidak tahu Bu.*

This research was also supported by a statement which stated that students could not relate the acid-base solution concept in everyday life. Therefore, this learning process requires more emphasis (Lathifa et al., 2015).

Percentage of Misconceptions on Acid-Base Materials

The tier four diagnostic test results vary widely. The results were then examined and analyzed to obtain the percentage of understanding the concept, not understanding the concept and misconceptions. The overall percentage of students could be seen in Figure 1 below:

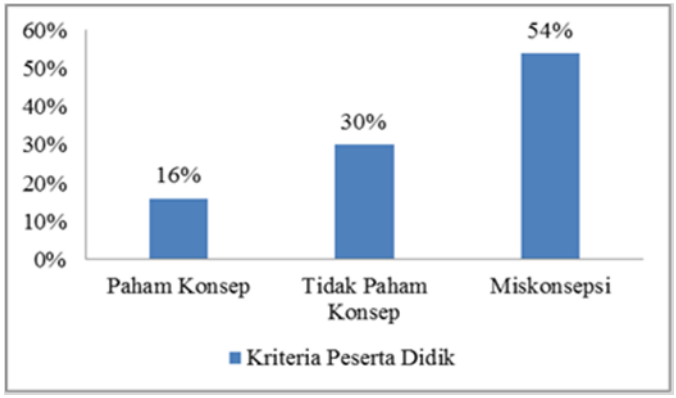

Figure 1. The Percentage of Students' Concepts Understanding

Figure 1 stated that the misconceptions category as 54% dominated the level of students' understanding. It showed that many students did not understand the acid-base material. The

percentage of students' misconceptions is shown in Figure 2. The 2 of 20 items tested had the highest percentage of misconceptions, namely items 10 and 11 with 67.6%.

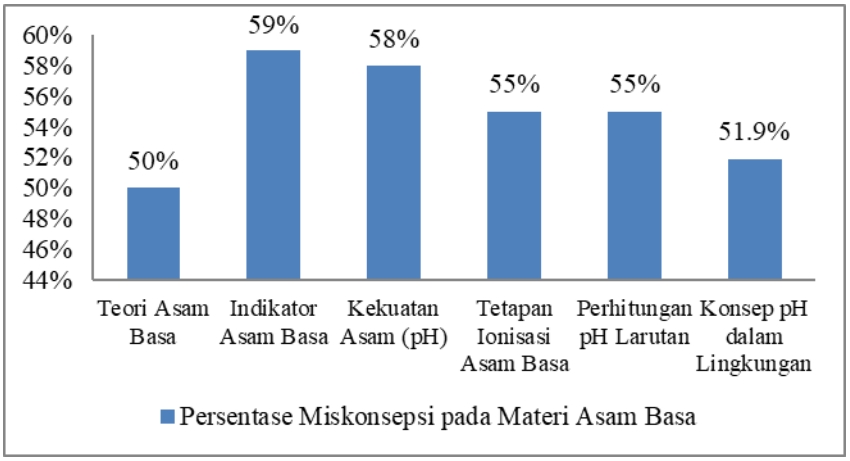

Figure 2. Percentage of Misconceptions on Acid-Base Materials

Figure 2 stated that the items regarding the acid-base theory concept had a percentage of 50%, acid-base indicators were 59%, acid strength (pH) was 58%, acid-base ionization (K_a/K_b) was 55%, calculation of solution pH was 55%, and the pH in the environment concept was 51.9%. So, the total misconception on acid-base material was 54%.

Misconceptions occurred because students could not correctly determine the Bronsted Lowry conjugate acid and base. They only focused on memorizing concepts without understanding the concepts. In addition, students could not determine acid-base indicators because they could not classify the acid and base solution characteristics. In the acid strength (pH) concept, students could not determine the base strength because they did not understand the definition of pH and the factors that affect its strength.

Furthermore, on the concept of acid-base ionization constants, students still had difficulty understanding the concept. They did not understand the previous material, namely chemical equilibrium. Students also could not understand the pH solution concept correctly because they had difficulty calculating it. It happened because the emphasis on concepts given by the teacher was still lacking. In addition, on the pH in the environment concept, students could not relate the acid-base solution concept to everyday life, so they had difficulty understanding the concept.

CONCLUSION

It can be concluded that the misconceptions of class XII MA students in Lamongan occur in all concepts of acid-base material, including acid-base theory, acid-base indicators, acid strength, acid-base ionization constants, solution pH calculation, and pH in the environment. These misconceptions include: 1) students think that blue litmus in an acid and base solution is blue, 2) students understand that the smaller concentration of OH^- ions, so the base is stronger, 3) students assume that the K_w value is higher than K_b, then the K_a value is lower than K_b, and (4) students understand that a base is a compound that accepts OH^- ions in water. The percentage of students' misconceptions about the acid-base theory concept is (50%), the acid-base indicator is (59%), acid strength is (58%), and the acid-base ionization constant is (55%), calculation of solution pH is (55%). The concept of pH in the environment is (51.9%).

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