



Analysis of Students' Misconception of Grade XI on Buffer Solution Material Using Three-Tier Multiple Choice Diagnostic Test Instrument

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Abstract:

This study aims to analyze misconceptions experienced by grade XI students on buffer solution material using a three-tier multiple-choice diagnostic test instrument. Misconceptions are one of the obstacles in the learning process, especially on abstract chemical concepts such as buffer solutions. A three-tier multiple choice diagnostic test instrument allows for deeper detection of misconceptions and distinguishing between correct understanding and misconceptions. This study was conducted at MAN 2 Lamongan with research subjects of grade XI MIPA students. This quantitative descriptive study involves 40 grade XI MIPA students who have studied buffer solution material. Research data were collected through a three-tier multiple-choice diagnostic test instrument. Data processing uses a percentage calculation technique, which is then grouped into three categories of understanding: understanding the concept, misconceptions, and not understanding the concept. The study results showed that students' misconceptions of buffer solution material occurred in all concepts with an average percentage of 36.5%, which is included in the moderate misconception category. The lowest misconception was identified in the buffer solution concept, with a percentage of 30.73%. Meanwhile, the highest misconception identified was the concept of buffer solutions being essential, with a percentage of 41.52%.

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Introduction

Chemistry is one of the subjects that emphasizes the mastery of concepts and calculations. This subject at the high school level applies three levels of representation: macroscopic, submicroscopic, and symbolic. The ability to describe the three representations is required to study and understand them well (Sagita et al., 2017; Hidayah et al., 2018; Sukmawati W, 2019). Buffer solutions are an example of a material with complex mathematical concepts and require somewhat complicated prerequisite concepts. Abstract concepts are related to acid-base reactions, chemical calculations are related to calculating the pH of buffer solutions, and prerequisite concepts must be mastered, such as acids and bases, equilibrium, and salt hydrolysis. This can cause students to have difficulty learning and understanding the material (Sanjiwani et al., 2018; Afifah et al., 2021; Genes et al., 2021).

Efforts to identify students' learning difficulties need to be carried out with a diagnosis directed at analyzing learning difficulties and the factors that cause them. This is important because an appropriate diagnosis will collect information about students' weaknesses and identify their learning problems (Inggit et al., 2021). Ultimately, it is essential to thoroughly understand the characteristics of the chemical material itself and make efforts to diagnose students' learning difficulties in understanding the concept. Both of these things have the potential to trigger misconceptions.

Misconceptions are differences between concepts held by students and expert communities. These misconceptions can come from several things, such as abstract chemical materials, teacher factors, the learning process, or textbooks used by students (Kustiarini et al., 2019). Misconceptions have the potential to become learning problems in the classroom if they are not addressed from the start (Priyasmika & Sholichah, 2022), prevent students from accepting new concepts (Gurel et al., 2015), and increase the scope of students' conceptual errors (A'yun et al., 2018). In addition to hurting learning outcomes, misconceptions will also impact students' understanding of subsequent chemical materials (Roza & Ramadani, 2023).

Several studies have shown that students experience misconceptions about buffer solution material, either in part or all of the concepts with various patterns (Nurhujaimah et al., 2016; Chozim et al., 2018; Nurhidayatulah & Prodjosantoso, 2018; Afifah et al., 2021). These results indicate that buffer solution material is prone to misconceptions. Therefore, efforts are needed to identify students' misconceptions as early as possible to determine students' conceptual understanding and minimize the possibility of broader misconceptions. Students' misconceptions can be corrected immediately. One of the instruments that can be used to identify misconceptions is the three-tier multiple-choice diagnostic test.

Three-tier multiple choice consists of three parts: the first contains questions that contain various answer choices, the second contains reasons that refer to the answers in the first part, the third contains the level of student confidence in answering the first level and the second level with response choices in the form of sure and not sure (Savira et al., 2019). The advantages of the three-tier include: 1) easy to use compared to other diagnostic tests, 2) simple instructions for working on it, 3) measuring students' confidence in their answers, and 4) suitable for use at the high

school level (Kustiarini et al., 2019). In addition, three-tier can also distinguish students who do not know the concept, misconceptions, or guess the answer.

Misconceptions hurt student understanding, can hinder the learning process in the classroom, and have the potential to cause misconceptions to emerge sequentially in the following chemistry material. Early identification of misconceptions will significantly assist teachers in describing chemistry concepts that require special handling or treatment in their learning. So, that teachers can consider and pay more attention to learning methods, the selection of teaching materials, and the use of more appropriate evaluation instruments. The next expectation is that misconceptions can be reduced and students' understanding of chemistry material in general will increase. Ultimately, this study aims to analyze the level and type of students' misconceptions about buffer solution material.

Research Method

The research method used is descriptive with a quantitative approach. The data and information obtained are then described as statistical figures related to misconceptions experienced by students in the buffer solution material. The subjects of this study were 40 students of class XI MIPA MAN 2 Lamongan in the 2023/2024 academic year who had been taught buffer solution material. The sampling technique used in this study was random sampling.

The data collection technique used was by administering a three-tier diagnostic test. This test is given to explore information on the level of students' understanding of the four concepts of buffer solution material, namely (1) buffer solutions, (2) essential buffer solutions, (3) acidic buffer solutions, and (4) calculating the pH of buffer solutions.

The three-tier diagnostic test instrument used was 15 questions developed by researchers with the division of concept 1 in questions number 1, 2, 3, and 4, concept 2 in questions number 5, 6, and 7, concept 3 in questions number 8, 9, 10, and 11, concept 4 in questions number 12, 13, 14, and 15. The results of instrument validation through expert validation showed an average value of 97.63%. The instrument trial was given to 25 students, and the test results using SPSS 16 obtained a question item validity value of 0.765. From all questions, it was included in the valid category. Data analysis begins by analyzing the results of students' answers to the questions given. The results of students' answers are then grouped according to the combination of three-tier diagnostic test answers and understanding categories as in Table 1.

Table 1. Understanding Student Category

Tier 1	Tier 2	Tier 3	Information
True	True	Sure	Understand the Concept
True	True	Unsure	Don't Understand the Concept
True	False	Sure	Misconception
True	False	Unsure	Don't Understand the Concept
False	True	Sure	Misconception
False	True	Unsure	Don't Understand the Concept
False	False	Sure	Misconception
False	False	Unsure	Don't Understand the Concept

(Ulandari, 2020)

The data from the categorization of understanding is then presented as a percentage to determine the level of misconception experienced by students. The criteria for the level of student misconception based on the percentage of misconceptions are shown in Table 2.

Table 2. Misconception Criteria

Misconception Percentage	Misconception Information
$0 < \text{Misconception} \leq 30\%$	Low
$30 < \text{Misconception} \leq 70\%$	Moderate
$70 < \text{Misconception} \leq 100\%$	High

(Simatupang, 2021)

Calculation of the percentage of misconceptions using the formula $P = \frac{S}{J_s} \times 100\%$

Explanation:

P = Percentage of students who understand the concept, do not understand the concept and misconceptions

S = The number of students who understand the concept, do not understand the concept and have misconceptions

J_s = Total number of students taking the test

Based on the percentage calculation results, an analysis was then carried out to determine students' misconceptions about the concept of buffer solution material. Descriptive analysis was also used to identify misconceptions in each question item.

Result and Discussion

Based on the data obtained using the three-tier test instrument, further analysis was carried out on the multiple-choice answers, the reasons for the answer choices, and the confidence level. The results were used to categorize students into three categories of understanding, namely understanding the concept (P), not understanding the concept (TP), and misconceptions (M) on the four concepts of buffer solution material shown in Table 3. The data on the understanding of the misconception category experienced by students per question item is shown in Table 4.

Table 3. Percentage of Student Understanding Categories (%)

Concept	Question Number	P	TP	M
1. Buffer Solution	1, 2, 3, 4	59,77	9,5	30,73
2. Basic Buffer Solution	5, 6, 7	49,25	9,23	41,52
3. Acidic Buffer Solution	8, 9, 10, 11	54,89	8,64	36,47
4. Calculation of pH of Buffer Solution	12, 13, 14, 15	51,94	10,77	37,29
Average		53,96	9,53	36,5

Table 4. Percentage of Student Misconceptions Per Question Item (%)

Question Number	Concept	Misconception Percentage	Average	Misconception Category
1	Buffer Solution	24,59	30,73	Medium
2		32,78		
3		26,22		
4		39,34		
5	Basic Buffer Solution	32,78	41,52	Medium
6		52,45		
7		39,34		
8	Acidic Buffer Solution	22,95	36,47	Medium
9		45,9		
10		40,98		
11		36,06		
12	Calculation of pH of Buffer Solution	37,7	37,29	Medium
13		49,18		
14		36,06		
15		26,22		

Based on the data in Table 3, it is known that the average percentage of students' understanding of the buffer solution material for the concept understanding category is 53.96%, the percentage of students who are in the category of not understanding the concept is 9.53%, and the percentage of students who experience misconceptions is 36.5%. In Table 2 regarding the misconception criteria, the misconceptions experienced by students in the buffer solution material are classified as moderate because the results are at a value of $> 30\%$ and $\leq 70\%$. The percentage of misconceptions experienced by students in the four concepts of the buffer solution material can also be seen in the graph in Figure 1.

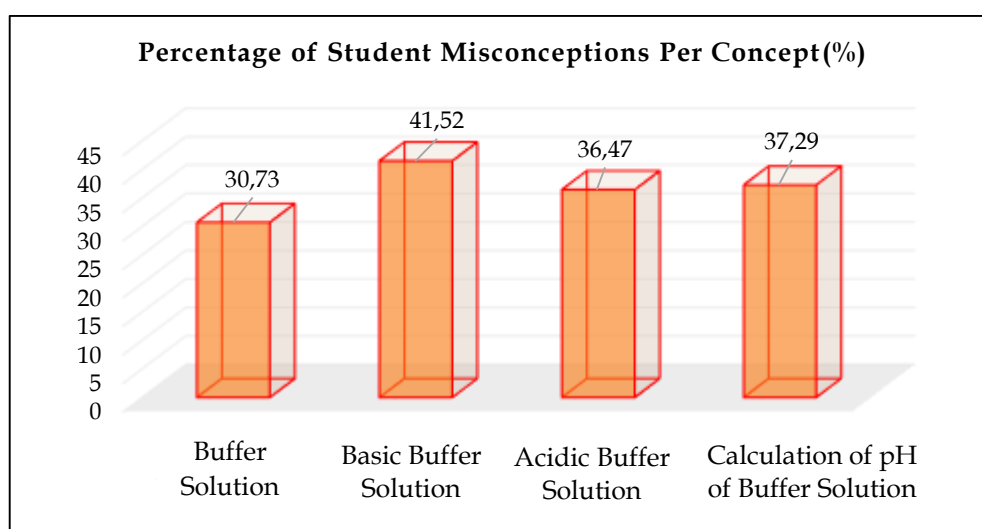


Figure 1. Graph of Percentage of Student Misconceptions Per Buffer Solution Concept

Figure 1 shows that the percentage of students' misconceptions about the concept of buffer solutions is 30.73%, and the concept has the smallest percentage of misconceptions. Misconceptions about the concept of essential buffer solutions are

41.52%, with the highest percentage of misconceptions. Furthermore, in succession, the misconception of the concept of acidic buffer solutions is 36.47%, and calculating the pH of buffer solutions is 37.29%. Students' misconceptions about the four concepts of buffer solution material are included in the moderate category of misconceptions. The percentage of students' misconceptions per question item across all concepts of buffer solution material is shown in the graph in Figure 2 below.

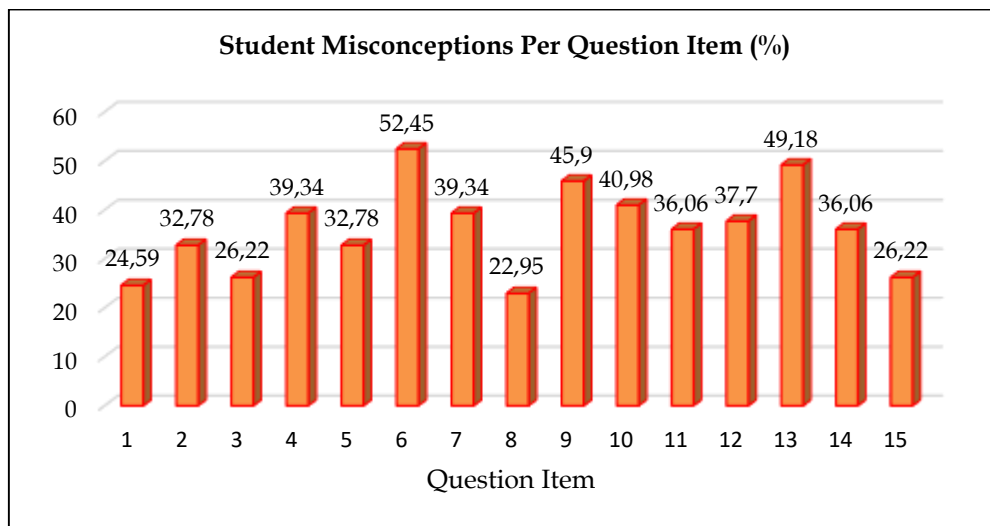


Figure 2. Graph of Percentage of Student Misconceptions Per Question Item

Figure 2 shows that the highest percentage of student misconceptions is in question number 6 on the concept of essential buffer solutions, which is 52.45%. At the same time, the lowest percentage of misconceptions is in question number 8 on the concept of acidic buffer solutions, which is 22.95%. In general, student misconceptions from 15 questions in 4 buffer solution concepts fall into the low and medium misconception categories.

1. Buffer Solution Concept

Questions 1, 2, 3, and 4 are questions on buffer solutions. The patterns of misconceptions experienced by students vary. Question number 1, the % of student misconceptions of 24.59%, is included in the low category of misconceptions because it is at a value of $\leq 30\%$. Students assume that buffer solutions can maintain the system's pH because the buffer capacity depends on the amount of acid and conjugate base that makes up the buffer. This is a misconception. After all, buffer solutions can maintain the system's pH because buffer solutions can maintain the pH in its range if a small quantity of acid or base is added or diluted.

Question number 2, the % of student misconceptions of 32.78%, is included in the moderate category. Students assume that an example of a buffer solution is $\text{CH}_3\text{COOH}/\text{CHOOH}$, where CH_3COOH is a weak acid compound and CHOOH is its conjugate base. This is a misconception because $\text{CH}_3\text{COOH}/\text{CHOOH}$ is not an example of a buffer solution.

Question number 3, the percentage of student misconceptions is 26.22%, which is included in the low category. Students assume that $\text{NH}_3/\text{NH}_4^+$ from NH_3 with

NH_4Cl is not a buffer solution pair because it combines weak acid and its conjugate base. This is a misconception because NH_3 is a weak base, and NH_4^+ from NH_3 with NH_4Cl is its conjugate acid.

Question number 4, the percentage of student misconceptions is 39.34%, which is included in the moderate category. Students assume that when adding water and strong acid to the buffer solution, the pH of the solution does not change drastically, which remains in the range of 2.48 after adding 2 mL of water and 2.32 after adding 2 mL of strong acid. However, after adding 2 mL of a strong base, the solution changes drastically to 13.45. However, students chose the correct reason: if a buffer solution is added with acid, base, or dilution in small amounts, the pH does not change significantly. The student's answer is a misconception because the buffer solution can maintain pH after adding a small amount of acid, base, or dilution.

This finding is similar to the research of [Nurhidayatulah & Prodjosantoso \(2018\)](#) which showed that students experienced misconceptions about the basic concept of buffer solutions by 43.37%. [Genes et al., \(2021\)](#) in their research, stated that students had difficulty understanding the concept of buffer solutions, with an average percentage of 83.7%. This is because students do not yet have a good basic concept from the previous material, which results in students' inability to understand more complex concepts.

2. The Concept of Basic Buffer Solutions

Questions covering the concept of essential buffer solutions are questions 5, 6, and 7, with an average percentage of 41.52% misconceptions, and they are the concepts with the highest misconceptions. Question number 5 has a percentage of misconception of 32.78%, which is included in the moderate category. Students assume that HOCl/OCl^- when given the addition of a small amount of strong base, the system's pH remains the same because the excess hydroxide ions in the solution will increase the acid concentration. This can be interpreted as students experiencing misconceptions because HOCl is a weak acid, and if a base is added, the concentration will decrease.

In question number 6, the percentage of student misconceptions is 52.45%, which is the question item with the highest misconception. Students assume that 100 mL of 0.1 M NaOH + 100 mL of 0.1 M HCN can form a buffer solution because buffer solutions can be made from strong bases and salts, but they are sure of the answer they choose. This can be interpreted as a misconception because buffer solutions cannot be made from strong bases and salts. It can be concluded that students do not yet understand the components of buffer solutions.

Question number 7, the percentage of student misconceptions is 39.34%, which is included in the moderate category. The pattern of misconceptions found in this question is that students assume that 100 mL of 0.2 M NaOH + 100 CH_3COOH 0.2 M with the reason that the reaction result of NaOH and HCN is $\text{NaCN} + \text{H}_2\text{O}$ where HCN is a weak acid and H_2O is a conjugate base. From these answers, it can be seen that students experience misconceptions because the first and second-level answers are unrelated.

3. The Concept of Acidic Buffer Solutions

The concept of acidic buffers is spread across questions 8, 9, 10, and 11. The average misconception in this sub-topic is 36.47%, including the moderate category. In question number 8, the percentage of student misconceptions is 22.95%, including the low category and the lowest misconception out of 15 questions. Students assume that CH_3COOH and CHOOH solutions are a pair of acidic buffer solutions because CH_3COOH and CHOOH are weak acids and their conjugate bases. CH_3COOH and CHOOH solutions are not buffer solutions because CH_3COOH is a weak acid, and CHOOH is a weak acid. Acidic buffer solutions consist of weak acids and their conjugate bases. This is a misconception that students cannot identify examples of acidic buffer solutions.

Question number 9, the percentage of student misconceptions is 45.9%, which is included in the moderate category. Students assume to find a mixture of 0.1 M NaOH solution and 0.1 M CH_3COOH solution with a total volume of 120 mL. The volume of each solution needed to make a buffer solution with a pH of 5 is by using the formula $[\text{OH}^-] = K_b \times a/g$, with excess weak acid volume. This is a misconception because to find a mixture of 0.1 M NaOH solution and 0.1 M CH_3COOH solution, which has a total volume of 120 mL with a pH of 5 using the formula $[\text{H}^+] = K_a \times a/g$, with excess substantial base volume. Each solution volume is 40 mL NaOH + 80 mL CH_3COOH .

Question number 10, the percentage of student misconceptions is 40.98%, which is included in the moderate category. In this question, students assume that NaHCO_3 with Na_2CO_3 are not buffer solutions, which is true. The reason is that NaHCO_3 with Na_2CO_3 is a weak base with a salt of a weak base, and that reason is not quite right because NaHCO_3 with Na_2CO_3 is not a mixture of buffer solutions because the salt of a weak acid and a strong base with a salt of a weak base.

In question number 11, the percentage of student misconceptions is 36.06%, which is included in the moderate category. The misconception in this question is that students assume a buffer solution can be made by mixing 100 cm^3 of 0.1 M CH_3COOH solution with 80 cm^3 of 0.1 M NaOH solution. The answer is correct, but students choose the wrong reason: the CH_3COOH solution is a weak acid, and the NaOH solution is a strong base with an excess strong base. Students are also sure of their answers. This is a misconception because CH_3COOH solution is a weak acid, and NaOH solution is a strong base. With excess weak acid 100 cm^3 of 0.1 M CH_3COOH = 10 mmol and 80 cm^3 of 0.1 M NaOH = 8 mmol, resulting in a remainder of 2 mmol of CH_3COOH , which means it is an acid buffer, so the excess volume should be a weak acid, not a strong base.

4. Concept of Calculating pH of Buffer Solutions

Questions 12, 13, 14, and 15 contained calculating the pH of buffer solution. The average percentage of misconceptions experienced by students in this sub-topic is 37.29%, included in the moderate category. In question number 12, the pattern of misconceptions found is that students assume that to find the pH of a weak base solution LOH, solid salt L_2SO_4 is added so that the concentration of the LOH solution becomes 0.1 M and the concentration of L_2SO_4 0.005 M is with $[\text{OH}^-]$ must be found first to find out pOH and pH. The answer is correct, but the student's calculation is incorrect; the pH obtained is 9.

In question number 13, the percentage of student misconceptions is 49.18%, which is included in the moderate category. In this question, students assume that to find the mass of a compound in the process of making a buffer solution consisting of 1 litre of 0.1 M acetic acid solution with a pH of 3, acetate salt is added until the pH is 2 times the original, students choose the reason for the volume of acetic acid solution multiplied by the concentration of acetic acid, and they are sure of the answer they choose. This is a misconception because the mass of a compound is determined by first finding the pH of the acetic acid solution, which is changed to the concentration of acid $[H^+]$ first multiplied by 2.

In question number 14, the percentage of student misconceptions is 36.06%, which is included in the moderate category. In this question, students assume that to find the mass of a mixture of buffer solutions consisting of $HCOONa$ (sodium formate) with a relative molecular mass of 68 and 100 mL of 0.1 M $HCOOH$ (formic acid) solution to obtain a pH of 4 is to use the formula $[H^+] = K_a \times a/g$, where $HCOOH$ is a weak acid, the answer is correct. However, the final result obtained is wrong. This indicates that students are not careful when calculating.

In question number 15, the percentage of student misconceptions is 26.22%, which is included in the low category. In this question, students assume that the pH of 50 mL of 0.1 M CH_3COOH solution mixed with 100 mL of 0.2 M CH_3COONa (K_a $CH_3COOH = 1.8 \times 10^{-5}$) can be calculated using the formula $[OH^-] = K_a \times b/g$, where the moles of acid are obtained from the volume of the solution multiplied by the concentration of the solution, as well as the moles of salt, CH_3COOH and CH_3COONa are base buffer solutions. This is a misconception because CH_3COOH and CH_3COONa are acid buffer solutions.

Other researchs result from [Kustiarini et al., \(2019\)](#); [Setiawan et al., \(2019\)](#); [Genes et al., \(2021\)](#) also mentioned something similar: Students experience misconceptions about calculating pH with different percentages. The lack of students' mathematical abilities in using pH and pOH calculation formulas and students' low accuracy in working on calculation problems are the causes of students experiencing learning difficulties ([Ulandari, 2022](#)).

Conclusion

Based on the results of data analysis, it can be concluded that the misconceptions experienced by students of class XI MIPA MAN 2 Lamongan on four concepts of buffer solution material are classified as moderate. The results of this study can be helpful as initial information to prevent ongoing misconceptions in subsequent chemistry materials considering the characteristics of chemistry, which are sequential and interrelated between concepts. So that teachers can describe and map chemistry materials that are prone to misconceptions. Teachers can then determine appropriate learning patterns in the classroom. Further research is still needed and is likely to be developed in other chemistry materials with more significant research subjects. Suggestions for further research are that the test instrument should be developed with a broader scope of concepts in order to identify misconceptions better. In the end, the opportunity for further misconceptions can be minimized, and remediation can be prepared.

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