JEC | Journal of Educational Chemistry
Journal of Educational Chemistry (4 (2), 2022, 99-108)
Website: https://www.journal.walisongo.ac.id/index.php/jec
ISSN 2715-3029 (p) 2685-4880 (e)
DOI: 10.21580/jec.2022.4.2.12687

Misconceptions About Buffer Solutions

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Abstract

There are many misconceptions in the chemistry discussion that can influence students to acquire new knowledge, one of which is regarding buffer solutions. It is one of the chemical concepts consisting of abstract ideas which likely trigger students' misconceptions. However, research on this topic was still limited. Thus, in the present study, researchers attempted to diagnose students' misconceptions about buffer solutions by administering a two-tier multiple-choice test. Research data were analyzed qualitatively and quantitatively. Respondents in this study were 98 second-semester eleventh-grade students majoring in Science in 3 senior high schools, with high (A), moderate (B), and poor (C) categories based on the 2015 National Examination's scores. The misconceptions detected were about what buffers do, what buffers are, and how buffers can do what they do. These findings were discovered in schools with a moderate category.

Keywords: chemistry; buffer solution; misconception

Abstrak

Banyak miskonsepsi yang terjadi tentang konsep kimia. Hal ini dapat mempengaruhi siswa untuk mempelajari pengetahuan baru. Larutan penyangga merupakan salah satu konsep kimia yang terdiri dari konsep-konsep abstrak yang mengakibatkan miskonsepsi siswa. Penelitian tentangnya masih jarang. Penelitian ini bertujuan untuk mendiagnosis miskonsepsi siswa tentang konsep larutan penyangga menggunakan pilihan ganda dua tingkat. Data dianalisis dengan menggunakan analisis kualitatif dan kuantitatif. 98 siswa kelas XI SMA program IPA semester 2 di 3 sekolah dengan kategori tinggi (A), Sedang(B), dan rendah(C) berdasarkan nilai ujian nasional tahun 2015 sebagai responden penelitian ini. Miskonsepsi yang terdeteksi adalah tentang apa yang dilakukan buffer, apa itu buffer, dan bagaimana buffer dapat melakukan apa yang mereka lakukan. Miskonsepsi terjadi di semua kategori sekolah dengan kategori sedang.

Kata kunci: kimia; larutan penyangga; miskonsepsi

Introduction

One of the Chemistry materials studied in X-class sciences is the Fundamental Laws of Chemistry. The concept of Fundamental Laws of Chemistry is based on principles concept and mathematics concepts (calculations). This material is a basic material that students must understand before studying Stoichiometry, Thermochemistry, Chemical Equilibrium, and Reaction Rate materials (Keenan, 1999). If the concepts contained in the material of the Fundamental laws of chemistry have not been understood by students, in that case, it might cause difficulties in the next learning process, especially when solving calculation problems. Therefore, it takes proficiency in understanding concepts and applying them in mathematical calculations (Zairida et al., 2019).

Chemistry is a subject that contains abstract concepts. This characteristic challenges students to understand relevant notions (Drastisianti, Susilaningsih, et al., 2018). There are three levels of representation in chemistry, namely: 1) the macroscopic level, which can be noticed in students' daily experiences, real and visible chemicals; 2) the submicroscopic level, regarding explanations about particles aimed to describe the movement of electrons, molecules, atoms; 3) symbolic, consisting of chemical symbols, formulas, equations, diagrams, models, and animations (Johnstone, 2000). Learners must have this proficiency to study chemistry. Hence, their lack of ability makes chemistry a complex subject (Siswaningsih et al., 2019; Üce & Ceyhan, 2019). Conceptual understanding is an essential factor in learning. Thus, teachers who apply traditional methods often make pupils passive and solely receive information. As a result, they find it difficult to understand the new concept (Drastisianti, et al., 2018), leading to misconceptions if those new ideas are against the views of scientists.

One of the learning challenges is a misconception (Mufit et al., 2018), which is a student's concept acquired through experience or informal education that is scientifically incorrect in its meaning (Soeharto et al., 2019). Misconceptions are also viewed as students' concepts that differ from the actual ones (Supatmi et al., 2019). Therefore, they result from learners using incorrect methods to acquire knowledge (Fadillah & Salirawati, 2018). In conclusion, a misconception can be used to define a learner's conception based on different interactions with scientists. It can impede the acquisition of new chemical concepts, which are taught hierarchically from simple to complex and easy to difficult. If students misunderstand simple or easy concepts, they will make mistakes with complex or challenging ones (Supatmi et al., 2019).

Misconceptions can be caused by various factors, including students' preconceptions based on prior experience, teaching methods, materials, books, and problem-solving related to complete comprehension, further referred to as school-based misconceptions (Barke, 2009). Chemistry misconceptions are believed to occur at all levels of education (Supatmi et al., 2019). Numerous studies uncovered misconceptions in chemistry, particularly concerning buffer solutions (Drastisianti, Wijayati, et al., 2018; Kusumaningrum et al., 2018).

Buffer solutions are chemical compounds that connect macroscopic, microscopic, and symbolic concepts (Johnstone, 2000). Students must associate macroscopic and symbolic knowledge with submicroscopic comprehension (Drastisianti et al., 2018). In addition, they must relate prior concepts such as chemical equilibrium, acid/base, stoichiometry, chemical reactions, and chemical solutions (Kusumaningrum et al., 2018; Orgill & Sutherland, 2008).

From the preceding information, numerous misconceptions have been uncovered. Moreover, those associated with buffer solutions were disclosed in several journal articles: Large amounts of acids and bases did not alter the pH of buffer solutions (Mutlu & Şeşen, 2016; Gani et al., 2017; Kusumaningrum et al., 2018); Weak acids and their salts could form a buffer, not a conjugate base (Mutlu & eşen, 2016; Gani et al., 2017); According to the Arrhenius acid-base theory, NH_3 was acid because it contained a hydrogen atom (H) and C_2H_5OH was base because it contained an OH group (Pikoli, 2020); HF and NaF solutions were expected to form a salt. It was a misconception because they were classified as buffer solutions (Septian et al., 2020); the mixture of NaOH and HCl was a mixture of buffer solutions (Ulfah et al., 2021).

Examples of misconceptions about how buffer solutions work include the following: if an acid/base was added to buffer solutions, the pH remained neutral (pH=7) (Mutlu & Şeşen, 2016; Gani et al., 2017); In buffer solutions, the element that remained was a strong base, so it was considered alkaline (Gani et al., 2017); The strength of buffer components would affect the strength of buffer solutions (Orgill & Sutherland, 2008).

A misconception is one of the challenges of learning chemistry. It must be eliminated because it hinders students' learning outcomes. Numerous techniques can be implemented for identifying misconceptions, including observation, description, fact and event interviews, conceptual interviews, word association, and diagnostic tests. In this regard, the diagnostic test can be a valuable input for chemistry knowledge and enhance teachers' instructional strategies (Hanson, 2019). It can assist instructors in identifying students' misconceptions about the discussed material and evaluating their grasp of the pertinent concepts. It may be administered through a multiple-choice test, interviews, two-tier multiple-choice, and three-tier multiple-choice (Rahmawan et al., 2021a). In this investigation, researchers used a two-tier multiple-choice diagnostic test.

Two-tier multiple-choice is a diagnostic test model consisting of two distinct structures. The first tier consists of core questions with five answer options, while the second tier focuses on the justifications for the answers given previously (Fadillah & Salirawati, 2018). This test can identify a large number of alternative concepts. Consequently, multiple studies have examined using a two-tier multiple-choice test in physics, chemistry, and mathematics instruction (Mutlu & Şeşen, 2016; Fadillah & Salirawati, 2018; Rahmawan et al., 2021). However, research on using a two-tier multiple-choice test to identify students' misconceptions about buffer solutions remains limited. Therefore, this study aimed to explore students' misconceptions regarding buffer solutions.

Method

This study employed a mixed research design. Based on the literature and chemistry curriculum, there were 15 questions concerning buffer solutions. Adopting the methodology of Chandrasegaran et al. (2007), the two-tier multiple-choice test was developed in three stages: Stage 1 consisted of defining the research content; Stage 2 comprised of mapping misconceptions about buffer solutions based on a literature review and student responses from other schools; Stage 3 contained designing the items and validating the two-tier multiple-choice test. Eight lecturers with expertise in language, media, content, and evaluation in learning participated in consultations regarding developing a two-tier multiple-choice test and its validity, both on the content using Aiken's formula and the suitability using the relevant developmental rules. Utilizing the Iteman DOS, the reliability, difficulty level, discriminating power, and distribution of distractor items of the developed two-tier multiple-choice instrument were tested at other schools. The participants in the present study were 98 eleventh-grade students majoring in the science program in senior high schools in the academic year of 2016-2017. They attended three schools with high (A), moderate (B), and poor (C) chemistry scores on the 2015 National Exam. The present study's two-tier multiple-choice instrument comprised questions regarding the buffer solution's definition, components, working methods, functions, and pH. Furthermore, a two-tier multiple-choice test was administered to evaluate and diagnose

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students' misconceptions. Subsequently, the results were analyzed based on Salirawati's (2013) research, as shown in Table 1, to calculate the percentage of their knowledge levels using the following equation.

Table 1
Analysis of Two-Tier Multiple-Choice Test (Salirawati, 2013)

First Tier	Second Tier	Category
Correct	Correct	Understood
Correct	No answer/explanation; partly correct	Partially understood
Correct	Incorrect	Misconception
Incorrect	Correct	Misconception
Incorrect	Incorrect	Not understood

Percentage of students' level of knowledge (Kusumaningrum et al., 2018):

$$= \frac{\text{The number of students in each concept}}{\text{Total number of students}} \times 100$$

The categories of misconception level can be seen in Table 2.

Table 2
Categories of misconception level (Fadillah & Salirawati, 2018)

Percentage	Category
$0 < \text{Misconception} \leq 30$	Poor
$30 < \text{Misconception} \leq 70$	Moderate
$70 < \text{Misconception} \leq 100$	High

Results and Discussion

Instrument Preparation

The two-tier multiple-choice diagnostic test's feasibility was described in detail as follows:

1. Content validity

In this study, the validation was conducted using Aiken's formula with the participation of eight raters: a linguist, a media expert, three expert lecturers, and three chemistry teachers. The purpose of the validation was to determine whether or not the instrument accurately measured students' misconceptions about buffer solutions. The value obtained depended on the eight raters mentioned previously. In particular, the lowest value was 0.75. As a result, the developed instrument was deemed feasible because each item had a value greater than 0.75.

2. Reliability

The alpha value obtained using the Iteman Dos analysis software determined this study's reliability. The first tier's reliability value was 0.934, and the second tier was 0.900, with a very high category. Therefore, the prepared research instrument was declared feasible.

3. Difficulty level

The difficulty level was indicated by comparing the proportion of students who answered correctly and the total number of students. The Iteman Dos analysis software was utilized to obtain the Prop. Correct values. In the first tier, there were 15 items with the medium level. Meanwhile, the second tier had 1 difficult-level item, 13 medium-level items, and 1 easy-level item.

4. Discriminating power

Discriminating power was described as the ability of the item to distinguish students with high and low abilities. Iteman Dos software was used in this analysis, relying on the point-biserial. The first tier categories were 1 moderate, 3 good, and 11 very good. Meanwhile, the second tier consisted of 3 good and 12 very good.

5. Distractor distribution

The distribution of distractors revealed the number of pupils with low and high abilities to answer questions. Multiple students were expected to choose an efficient distractor. In this study, the Iteman Dos alternative statistics feature was used to analyze the distribution of distractors. According to the analysis results, all first- and second-tier question scores were negative, indicating that all distractors were effective. Therefore, the instrument could diagnose student misconceptions based on the above analysis.

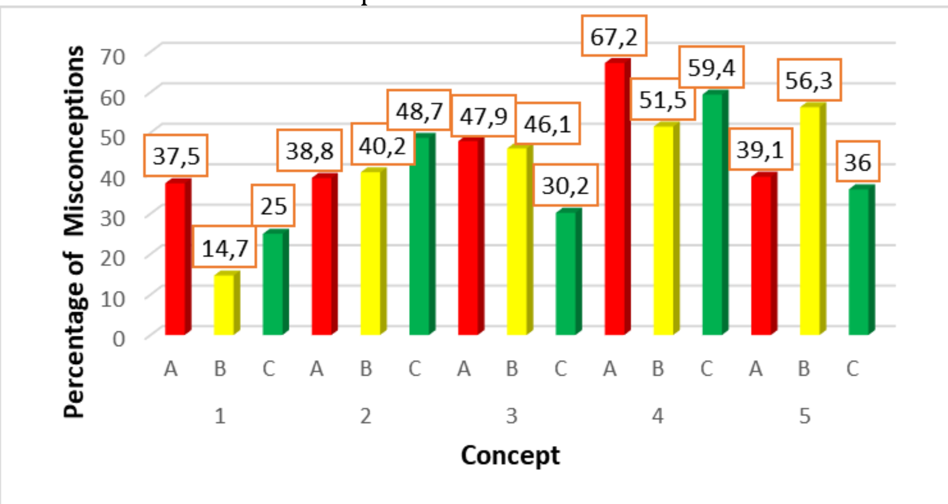
Misconception Analysis

Based on the interpretation of students' answers, the percentage of misconceptions about buffer solutions can be seen in Table 3 and profile of students' misconceptions was provided in Figure 1..

Table 3
Percentage of Students' Misconceptions about Buffer Solutions

Concept	School	Number	Percentage of Misconceptions
Definition of buffer solutions	A	1	37.5
	B		14.7
	C		25.0
Components of buffer solutions	A	2, 4, 5, 6, 7, 12, 13	38.8
	B		40.2
	C		48.7
How buffer solutions work	A	3, 8, 9	47.9
	B		46.1
	C		30.2
Function of buffer solutions	A	10, 11	67.2
	B		51.5
	C		59.4
Calculation of the pH of buffer solutions	A	14,15	39.1
	B		56.3
	C		36.0

Figure 1
Profile of Students' Misconceptions



Based on Table 3 and Figure 1, researchers concluded that the highest percentage of misconceptions varied across all categories. The highest

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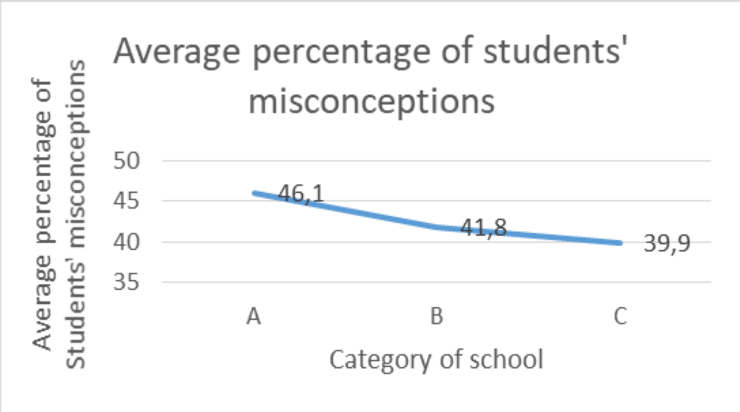
misconception regarding the function of buffer solutions occurred in schools classified as high and poor quality. In schools in the moderate category, the pH calculation of buffer solutions revealed the highest misconception. Figure 2 summarizes the average percentage of student misconceptions at each school.

Figure 2
The Average Percentage of Students' Misconceptions



All schools had a moderate category of misconceptions based on the data above. Schools with the lowest percentage of misconceptions were those classified into the poor category (39.9%), followed by schools with the moderate (41.8%) and the high (46.1%) categories.

The first misconception pertained to the definition of buffer solutions and was prevalent across all school categories. Many students believed that the pH of buffer solutions was constant because a textbook they read defined buffer solutions as substances that maintain the pH. Thus, they assumed that the solution's pH would remain constant regardless of how much acid or base was added. It was supported by the results of interviews with students, which revealed that they understood that the components of buffer solutions could withstand the pH regardless of the addition of acid or base. However, they did not comprehend the amount of acid or base added to buffer solutions to maintain the pH. This misconception was consistent with the findings of Mutlu & Şeşen (2016), Gani et al. (2017), and Kusumaningrum et al. (2018). Others believed that buffer solutions were composed of a strong acid and a strong base combining to form a neutral solution. It was aligned with Mutlu and Şeşen's research (2016). These results might also be affected by the lack of conceptual clarity in the textbooks read by students. Consequently, they were unable to comprehend the concepts thoroughly.

The second misconception concerned the components of buffer solutions; seven questions were pertinent. They consisted of a weak acid/base conjugate and its conjugate base/acid, which contributed to maintaining a solution's pH. This type of misconception occurred in all school categories. Initially, some students believed that mixing a weak acid with a strong base could only create buffer solutions. Per Orgill & Sutherland (2008), it was the most significant misconception in this context. The formation of buffer solutions is possible if the amount of weak acid/base added is greater than that of strong acid/base. The second misconception involved buffer solutions, which were thought to be composed of weak acid/base and conjugate salts. It accorded with Mutlu & Şeşen (2016). Buffer solutions are composed of a weak acid/base and a conjugate base/acid. The students also concluded that $H_2PO_4^-$ and HPO_4^{2-} could not form buffer solutions because they were both ions. The final misconception engaged the belief that buffer solutions could form a strong acid/base, resulting in a neutral solution. This issue was likely caused by textbooks and students' preconceived notions, as some of their textbooks described the components of buffer solutions as a weak acid/base and a conjugate salt.

The third misconception pertained to how buffer solutions function, which occurred in all school categories. It was discovered that adding a stronger base to buffer solutions neutralized the pH because the existing components could maintain it. This misconception was confirmed by Mutlu and Şeşen (2016). According to Orgill and Sutherland (2008), students believed that a small amount of acid/base added to a weak base/acid could increase/decrease the solution's pH. In addition, if a strong base were added to OH^- buffer solutions, it would react with H^+ to produce H_2O. More H+ was present, thereby maintaining the pH change. This misconception arose due to students' misunderstanding of the concept of equilibrium.

The fourth misconception focused on the function of buffer solutions. There were still misconceptions when students described why buffers could withstand intracellular and blood pH, even though they could already explain the relevant intracellular and blood functions. It appeared because they misunderstood how buffer solutions and chemical equilibrium perform, consistent with Orgill & Sutherland (2008).

The final misconception was about calculating the pH of buffer solutions, which was prevalent in all educational institutions. Students encountered the misconception that the pH of buffer solutions would remain unchanged if a small amount of strong acid/base were added. Therefore, they disregarded the moles of strong acid/base applied. Nevertheless, the pH of buffer solutions was relatively stable.

There were misconceptions regarding the definition, components, working methods, functions, and calculation of buffer solutions' pH. They were uncovered at all moderate-level schools. Based on an analysis of written test answers and interviews, students and textbooks were the primary sources of misconceptions. They were inclined to memorize without understanding the discussed concepts. To reduce the number of misconceptions among students, teachers needed to implement engaging learning methods and strategies that connected the pertinent topics to events in the surrounding environment. Educators must also administer a pretest before learning to identify students' misconceptions.

Conclusion

The results of the present study indicated that the two-tier multiple-choice test was a valuable means of detecting students' misconceptions about buffer solutions. The misconceptions above were identified in all discussions regarding buffer solutions and at all schools in the moderate category. In this regard, schools in the highest category had the highest proportion of students with misconceptions. Therefore, it could be a topic for remedial learning. Two-tier multiple-choice questions could also acknowledge students' ideas regarding buffer solutions to be discussed in class, fostering an active learning environment. In addition, misconceptions about buffer solutions were also caused by educational materials, primarily textbooks, which essentially provided insufficient explanations of the subject matter, causing students to develop misconceptions.

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