Cross-sectional approach for diagnosing student’s learning progression in relation to pre-requisite knowledge of buffer solution

Z Fitriza¹, F Q Aini¹, and P Handayani¹
¹Chemistry Department, Universitas Negeri Padang, Padang, Indonesia
Prof. Dr. Hamka Street Air Tawar, Padang, West Sumatera, Indonesia 26171

*zonaliafitriza@fmipa.unp.ac.id

Abstract. Buffer Solution is one of the complex concepts in chemistry since it involves many prerequisite concepts such as acid and base, chemical equilibrium, and stoichiometry. These concepts also need sequent students’ understanding of the chemical equation, chemical nomenclature, and atomic symbol. Their difficulty in comprehending prerequisite knowledge will affect the learning progression. This research aims to diagnose learning progression and the causes of the learning progression block of senior high school students on the buffer solution. Learning progression of 82 X grade, 80 XI grade, and 80 XII grade students were identified by a structured diagnostic test of chemistry using a cross-sectional approach. This research figure out that the learning progression of the student was not as expected since they cannot mastering buffer solution well particularly in buffer solution component, pH of buffer solution, and pH maintaining mechanism because of their difficulty in understanding chemical equilibrium and ionization reaction.

1. Introduction

Many research about buffer solution found that many students have difficulties in understanding the concepts. These difficulties including misconception about some buffer solution concepts such as the component of buffer solution, how buffer maintaining the pH, determining the pH of buffer solution after addition of acid and base, and the capacity of buffer solution[1–4]. It happen when the prerequisite knowledge of students did not match with their learning experience[5].

Prerequisite knowledge will affect students understanding of the buffer solution concept due to the chemistry concept will construct from the fundamental chemical concept when students starting to learn chemistry[6,7]. Misunderstanding of prerequisite concepts on buffer solution are solution concept, the chemical equation, stoichiometry, acid and base, chemical equilibrium, ionization reaction, the strength of acid and base, mathematical calculation, particle characteristic of matter[1–3,8]. Besides, the learning experience also takes an important role to revise the misconception or even causing the next misconception.

The students’ prerequisite knowledge will combine with learning experience during the learning process. The learning experience could be the material that they get from teacher explanation, book, friends or other learning environments[9]. It will happen when they start learning chemistry at the lower
grade to a higher level. They will experience the learning progression since many materials will improve from time to time begin from basic concepts to the complex concept during the learning process[10].

Learning progression is shown as an effort to identify basic science ideas of students and the development of student understanding to provide a suitable teaching-learning process[11,12]. The learning progression aligns with the constructivism theory that student understanding is constructed from simple knowledge to the complex one[13]. The learning progression is done through the process in Figure 1 below.

![Figure 1. Learning progression process[14]](image)

Figure 1 illustrates the process of knowledge construction from the basic knowledge that changes to be intermediate 1, 2, and so forth and then they get their scientific knowledge. The intermediate knowledge is affected by the basic concept, prerequisite, and learning experience that students have which are called complexity and inclusivity. Complexity is the relevance of knowledge addition with previous knowledge while inclusivity is some new aspect given during the learning process that could trigger alternative knowledge or called misconception[14].

At the beginning of learning chemistry, Indonesian students learn about the atom, naming of the atom, ion, molecule, mole, molarity, equilibrium reaction, Kc, Le-Chatelier Principle, weak acid, weak base, conjugate acid, conjugate base, pH, and then buffer solution. Those concepts are learned from Junior High School about atom and element and then deeper learning in X grade in Senior High School about the atom, element, chemical nomenclature, mole concept, molarity, chemical reaction. It then continues to the first semester of XI grade about equilibrium reaction, Kc, and Le Chatelie Principle. In the early second semester before learning the buffer solution, the student learns about acid and base first.

This research diagnosed the learning progression of students about buffer solution concepts and figure out the prerequisite knowledge which blocks their learning progression or causing misconception. This information will encourage us to emphasize certain prerequisite knowledge to result in the learning progression.

2. Method
This research was conducted through a cross-sectional research design that was collected on one or more variables for a single period[15]. Data were obtained at one point in time from students of different ages or different grade levels. The cross-sectional test was conducted on the students at a different level.

The test had given to 242 senior high school students which consist of 82 X grade students and 80 XI and XII students. They were given a structured diagnostic test of chemistry (SEDToC) for the topic buffer solution. This test consists of two sets of questions about acid buffer and base buffer solution. It
The learning progression of students on buffer solution and it’s prerequisite concepts are divided into concepts about atomic symbol and name, chemical nomenclature, stoichiometry, ionization reaction, is arranged as a sequence question from a basic concept about atom to the complex concept about buffer solution. Besides this test also require student’s understanding of the chemical phenomenon and molecular explanation about the phenomenon called multiple representations of chemistry proposed by Johnstone[16].

The SEDToC was investigated the student learning progression using a cross-sectional approach. Besides, it also checked the concept which triggers misconception and difficulties in learning buffer solution since it was developed sequent that make student cannot continue their answer before they answer previous related questions. For example, the student will not able to answer the product of the reaction when they cannot answer the reactants involved.

The student answer was coded as 1 if they answer the question correctly and 0 when they did not answer the question or answered it wrong. 1 and 0 will not count quantitatively because 1 and 0 are the ordinal data which means it has a rank ordering but not that the consecutive ranks represent unit intervals. This data only classify into the correct answer and incorrect answer then analyzes deeper to conclude the learning progression pattern.

The data that was collected from the test was then analyzed using Miles and Huberman [17] that consist of data reduction, data display, and conclusion. The process is shown in Figure 2.

![Figure 2. Flow model of Miles and Huberman analysis](image)

2.1. **Data reduction**
Data reduction is summarizing, selecting the main problem, focusing on important information to find the pattern of the students’ answers. It also an analysis that sharpening, reducing, focusing, selecting, and organizing the data to give clear information. In this research, the data found were classified into correct and incorrect that then percentage the right and wrong answer to decide there is a blockage in the learning progression or not.

2.2. **Data Display**
After data reduction, the data was presented and organized as a table and graph to make it easier to understand. Based on the data display, the pattern of learning progression from the lower level to a higher level of students will be easier to conclude.

2.3. **Conclusion and Verification**
Conclusions will show as analytic text or narrative that relates one to other information from data display. It will produce an interpretation of the analyst and conclude it using supported reference. It will also come as a clarification of the previous conclusion made.

3. **Result and Discussion**
The learning progression of students on buffer solution and it’s prerequisite concepts are divided into concepts about atomic symbol and name, chemical nomenclature, stoichiometry, ionization reaction,
chemical equilibrium, and buffer solution itself. The question in the diagnostic test was arranged based on these concepts since they relate each other. For instance, when the students do not know the atomic symbol, it will make them hard to understand chemical nomenclature. Then, when they have difficulty in naming the substance, they will have to apply chemical equations, ionization reactions, and chemical equilibrium. It will affect much to their understanding about buffer solution due to the concept need knowledge about stoichiometry and chemical equilibrium.

The data found from the test was summarized in Figure 3 below. This chart presents the learning progression of the student with a cross-sectional approach that was conducted to X, XI, and XII grade senior high school students. Based on the data, the learning progression for each prerequisite and the buffer solution concept can be identified and the causes of the learning difficulty which means the blockage of the learning progression can also be identified.

3.1. Learning progression and its blocking
The students’ understanding of these concepts was generally increasing as shown in Figure 3. All concepts except the atomic symbol and atomic name showed the learning progression of students. It aligns with their learning experience. In X grade the students do not learn chemical equilibrium, acid base, and buffer solution. Therefore, it is normal when the X grade students cannot answer these questions because they do not have any experience with these concepts. However, the concept of atomic symbol and the atomic name was the only one concept that shows a decreasing trend. It is the basic concept that students learn from the beginning they learned about chemistry. It started from junior high school which means the X grade students already have the experience in learning these concepts and also XI and XII grade students have more experience to learn about this. However, the number of students who understand about atomic symbol and name tended to decrease slightly.

The concept of chemical equilibrium seems to have low students’ understanding either for X, XI or XII grade students. There are less than 30% of XII grade students who can answer the question about chemical equilibrium, and of course, it will impact their understanding of buffer solution. It also very low achievement in XI grade students for both concepts.

The details about some of the specific concepts about the seven topics above are represented by Table 1. The first line data for each detail concepts relate to a set of questions about acid buffer while the second line for base buffer. Both sets of questions represented the same detail concepts.
Based on Table 1, the students struggle to understand buffer solution although it shows that there are progressions from X grade that can’t answer any question about buffer solution. In XI grade the students have better performance in understanding buffer solution than X grade and so do with XII grade students who have the best achievement. Unfortunately, the progression was not in the expected achievement. Most of the students in X grade, XI grade, and XII grade have difficulty in understanding the concept.

The worst is in Le Chatelier principle and pH maintaining mechanism of buffer solution and even worse is in determining the pH of the buffer solution.

The students who can determine the pH of the buffer solution of less than 5%. Although many of them were understand how to apply the stoichiometry concept, nevertheless, they need to know the component of the buffer which affects the pH of the solution. The buffer solution consists of a weak Bronsted acid and a weak Bronsted base to resist large changes in pH when small amounts of acid or base are added. Their difficulty in determining of buffer solution pH is not because of their stoichiometry concepts, but because of their misunderstanding about the buffer component which affects the pH of the solution.

Le-Chatelier principle and the pH maintaining mechanism of buffer solution are the concepts that need to emphasize since the students who understand between 8 to 12 % of XII grade students and the lower level students who can answer the questions related to this are less than that. Although there were progressions from the lower level to the highest level students, however, the percentage shows that most students possess some problem in learning these concepts. The identified problem in this research was about their knowledge about chemical equilibrium. When the students learn about the pH maintaining mechanism of buffer solution, they will apply the Le-Chatelier principle. Le-Chatelier concept explains about chemical equilibrium when a buffer neutralizes either a strong acid or a strong base that added to the system. The neutralize process occurs because the buffer component reacts with acid or base added and the reaction will shift to undo the disturbance in the equilibrium system.
Since they do not understand about buffer solution, most students cannot explain the chemical phenomena at the submicroscopic level. They can not draw what particles exist before and after the addition of acid or base in the buffer solution. It happened because they did not know the buffer component, they can not apply the chemical equilibrium and ionization reaction.

3.2. Misconception

The learning progression indicates that students’ knowledge develops from basic knowledge to the complex ones [12]. The information about this will help the teacher to begin the next teaching-learning process to make their students reach the target concepts. Problematic concept (misconception) in buffer solution topic shows that their knowledge is not developed well to the complex concept.

Some misconceptions which are the blocking of learning progression were identified from the students’ answers. First misconception was found in writing the element symbol which they answer as the molecule. For instance, they answered the element symbol of hydrogen and oxygen as H₂ and O₂ respectively which are the molecular formula of the compounds that are shown in Figure 4.

Question 1.1 Write the appropriate atomic symbol of chemical elements below
Carbon b. Hydrogen c. Oxygen d. Sodium e. Chlor

![Figure 4. Example of a students' misconception about the atomic symbol](image)

That answer shows that the students did not know the difference between element, compound, and their smallest unit. It can understand that hydrogen and oxygen both for elements and compound spell in the same name.

The second misconception was in the application of the stoichiometry concept. In question 1.3 the students were asked about the mole of acid and base with volume and molarity given, however many students answer it as mill mole. Some of the students’ answers are correct as of the mathematical calculation but do not like a mole concept. Some others failed to relate volume and molarity variables to apply the stoichiometry concept. The example of students’ misconception as Figure 5 below.

Question 1.3. Calculate the mole of
100 ml of methanoic acid 0.1 M
50 ml of sodium hydroxide 0.1 M

![Figure 5. The examples of misconception about the mole concept](image)
The third was their difficulty in solving the problem of the chemical reaction. In this part, the equation is the reaction of acid and base to form salt and water since the buffer solution consists of weak acid or base and its conjugate which comes from salt ionization. Their answers demonstrate that many of them can write the reactant and the symbol of reaction, nevertheless they failed to understand the concept of salt. Many of them only know the salt as sodium chloride or table salt, however in chemical concept salt is the ionic compound that is produced by acid and base reaction such as NaCl, K₂SO₄, CaCl₂, etc.[18]. Besides, some others have difficulty in predicting the ion of acid and base that bond each other to form the salt. Their misconceptions are written as the Figure 6.

Question 1.4. Write the reaction of methanoic acid with sodium hydroxide to form salt and water!

![Figure 6](image)

Figure 6. The example of students’ misconception about chemical reaction (a) The first example of students’ answer (b) The second Example of students’ answer

![Figure 7](image)

Figure 7. The example of the correct answer of the student about chemical reaction

The fourth is about ionization reaction which relates to the previous concept about chemical reaction. When the students’ unsuccessful in comprehend the chemical reaction, they will fail to answer the next question. Figure 8 below shows the example of students’ misconceptions about ionization reaction. The students who grasp the chemical reaction have responded to the question about ionization reaction correctly except the ionization reaction of water. Many of them presume that the ion exists in water are H⁺ and O₂⁻ ion. One molecule of water will be ionized to be H⁺ and OH⁻ ion among 10,000,000 molecules of water[19]. There were also misconceptions about the reversible and irreversible reactions of the substance involved in the reaction from the previous question. Some students assume that the ionization of methanoic acid is irreversible while it is an equilibrium reaction. Otherwise, some others believe that sodium methanoate is the reversible reaction, but it is not. The example answers are presented in Figure 8.

Question 1.5. Write the ionization reaction of A, B, C, and D compound based on your answer in question 1.4!

![Figure 8](image)

Figure 8. The example of students’ misconception about ionization reaction (a) The first example of students’ answer (b) The second example of students’ answer
The decrease of students’ understanding about buffer solution was caused by chemical equilibrium misconception. It was initiated by their impediment in ionization reaction, then continue to Le-Chatelier Principle. They did not understand how the buffer solution maintains the pH when it is added by a little number of acid or base, which component of a buffer solution that will react with added substance to keep the pH value steady, and how the Le-Chatelier principle is applied in the reaction. When a buffer solution is added by a little number of acid it means the H⁺ ion which will be affected to the pH value is reacted to the conjugate base and the reaction will shift to the reactant or product to undo the addition of H⁺. The same process will happen to the addition of base or OH⁻.

\[
\text{HCOO}^{-(aq)} + \text{H}^+(aq) \rightarrow \text{HCOOH}(aq) \\
\text{HCOOH}(aq) + \text{OH}^-(aq) \rightarrow \text{HCOO}^- (aq) + \text{H}_2\text{O}(aq) \quad [18]
\]

The next misconceptions were about buffer solution concepts that are about buffer solution components, pH of buffer solution, and pH maintaining mechanism of buffer solution. The students who comprehend these only the students who understand of the chemical equilibrium. When they asked about the buffer solution component, many of them answered that it is consists of the weak acid and strong base or weak base and strong acid. It will affect their understanding about the sub-microscopic phenomenon. Johnstone proposed three representation of chemistry that are micro-level means the phenomenon that was seen as a fact, the sub-microscopic level which shows the molecular level of phenomenon happened and symbolic as the reaction or chemical symbol [16]

Unfortunately, fewer students can draw the buffer solution at the molecular level. A few of their answers are shown in figure 9 below. Figure 9 illustrates their thinking about the buffer solution component which the first draw shows that the student view that the buffer solution consists of HCOOH, HCOO⁻, Na⁺, and H⁺ by ignoring the ionization of water. The second and third draws present their belief that the buffer solution also consists of the strong bases.

![Figure 9. Variation of students’ answer about the sub-microscopic level of buffer solution](image)

Other misconceptions were about pH calculation and pH maintaining of buffer solution. The expected answer about pH calculation comes from the equilibrium reaction that is derived to find the pH formula and pH value. However, all of them who answered it use the formula that they memorize. Their answers can come from the teacher explanation or book that they read. Even though they answer it correctly as a mathematical calculation but it better for them to understand the pH value based on the reactions involved in the buffer solution. So that they can understand the role of H⁺ in the solution. The effect of the memorizing the equation, they misunderstand which equation is suitable to use. Some of the students use the equation to determine the pH acid and base, not the equation to determine the pH value of the buffer solution. When people memorizing something, it will save in short-term memory that will lose in an instant. They need to understand and connect some of the variables including their prior and prerequisite knowledge that they have to make them learn meaningfully. It will then save in long-term memory which will stay longer in memory and easier to recall [20,21]. The example of students’ failure is shown in figure 10.
Question 1.9. Calculate the $H^+$ ion concentration when the $K_a$ of methanoic acid as $1.8 \times 10^{-4}$.

Example of student’s misconception

$$H^+ = \sqrt{K_aC} \Rightarrow H^+ = \sqrt{1.8 \times 10^{-4}C}$$

**Figure 10.** The misconception of students about the pH of the buffer solution

Question 1.10. Based on the concentration of $H^+$ that you found in the previous question, calculate the pH of the buffer solution!

$$pH = -\log[H^+] = -\log(1.8 \times 10^{-4}C)$$

**Figure 11.** The misconception of students about the pH of the buffer solution

4. Conclusion

Students’ comprehension about buffer solution concepts did not progress as expected especially in the concept of buffer solution component, pH of buffer solution, and pH maintaining mechanism of buffer solution. These are due to students’ difficulties in prerequisite knowledge which are chemical equilibrium, ionization reaction, and stoichiometry. Many misconceptions happened in these concepts. Moreover, most students could not explain the buffer solution phenomenon at the molecular level whereas this knowledge is very important when talking about chemistry. Teachers have to concern about the problem and overcome it through a suitable teaching-learning strategy that will make prerequisite knowledge and the targeting knowledge connect each other.

Acknowledgments

The authors would like to express deep gratitude to Universitas Negeri Padang for funding this research. We are also thankful to Headmasters and the students of Senior High Schools in Payakumbuh, West Sumatera, Indonesia who had allowed us to conduct this research.

References

[1] Kusumaningrum et al 2017 Scientific Approach and Inquiry Learning Model in the Topic of Buffer Solution: A Content Analysis Scientific Approach and Inquiry Learning Model in the Topic of Buffer Solution: A Content Analysis Int. Conf. Math. Sci. Educ. (ICMScE). IOP Publ. 12042

[2] Andriani N, Munira I and Fitriza Z 2019 Diagnosa Hubungan Pengetahuan Awal (Prior Knowledge) Terhadap Kesulitan Belajar Siswa Pada Materi Larutan Penyangga Di SMA N 1 Solok 3 26–31

[3] Handayani P, Munira I and Fitriza Z 2019 Analisis Hubungan Kesulitan Belajar dengan Pengetahuan Awal (Prior Knowledge) Siswa Menggunakan Tes Diagnostik Two-Tier pada materi Larutan Penyangga di SMAN 2 Solok 3 32–9

[4] Drastisianti A, Wijayati N and Susilaningisih E 2018 Identification of misconceptions on buffer material using three-tier test in the learning of multiple representation J. Innov. Sci. Educ. 7 95–100

[5] Taber K S 2016 The Use of Cronbach’s Alpha When Developing and Reporting Research Instruments in Science Education
[6] Nakhleh M B 1992 Why some students don’t learn chemistry: Chemical misconceptions J. Chem. Educ. 69 191–6
[7] Orgill M K and Sutherland A 2008 Undergraduate chemistry students’ perceptions of and misconceptions about buffers and buffer problems Chem. Educ. Res. Pract. 9 131–43
[8] VAN DRIEL J H 2002 Students’ Corpuscular Conceptions in the Context of Chemical Equilibrium and Chemical Kinetics Chem. Educ. Res. Pr. 3 201–13
[9] Widiyatmoko A and Shimizu K 2018 Literature Review of Factors Contributing to Students’ Misconceptions in Light and Optical Instruments 13 853–63
[10] Corcoran T, Mosher F A and Rogat A 2009 Learning Progressions in Science. An evidence-based Approach to Reform Consort. Policy Res. Educ. 86
[11] Duncan R G and Rivet A E 2013 Science learning progressions Science (80-. ). 339 396–7
[12] Anon 2012 Alonzo, C Alicia & Amelia Wenk Gotwals. 2012. Learning Progression in Science: Current Challenges and Future Directions. Netherlands: Sense Publishers. 2012
[13] Johnson P and Tymms P 2011 The emergence of a learning progression in middle school chemistry J. Res. Sci. Teach. 48 849–77
[14] Park E J, Light G, Swarat S and Denise D 2009 Understanding learning progression in student conceptualization of atomic structure by variation theory for learning Learn. Progress. Sci. Conf. 1–14
[15] Menard S 2008 Introduction: Longitudinal research Design and analysis Longitudinal Research Design, Measurement, and Analysis ed S Menard (Colorado: Elsevier Inc.) p 665
[16] Hussein F and Reid N 2009 Working memory and difficulties in school chemistry Res. Sci. Technol. Educ. 27 161–85
[17] Anon 1994 Miles, Matthew dan Michael Huberman. 1994. Qualitative Data Analysis: Expanded Sourcebook 2nd Edition . United States of America: Sage Publications. An 1994
[18] Brady, James E, & Senese F 2009 Chemistry ed S Jhonson (New York: John Wiley & Sons, Inc)
[19] Petrucci R H, Herring F G, Madura J D and Bissonnette C 2011 General Chemistry Principles and Modern Application (Toronto: Pearson Prentice Hall.)
[20] Mayer R E 2014 What Problem Solvers Know: Cognitive Readiness for Adaptive Problem Solving Teaching and Measuring Cognitive Readines ed E L Baker (New York: Springer Science+Bussiness Media) pp 149–60
[21] Mayer R E, Lee H and Peebles A 2014 Multimedia learning in a second language: A cognitive load perspective Appl. Cogn. Psychol. 28 653–60