



Promoting Multiple Representation in the TPACK Framework to Clarify the Acid-Base Species Problem-Solving

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Abstract

Oversimplifying chemical concepts to explain the invisible part is frequent in the concept of acid-base species determination. During school time, teachers frequently drill students to use straightforward formulas to prevent time-consuming calculations in calculating pH values. This attitude contributes to misleading problem-solving even among twenty-three preservice teachers at one of the educational universities in West Java, Indonesia. Therefore, the lecturer developed a learning strategy that uses the TPACK framework and multiple representations to clarify the misleading and prepare chemistry preservice teachers to overcome similar challenges in real-world situations. The multiple representations and misconceptions analysis was assigned to determine a suitable pedagogical strategy and identify appropriate technology. Quantitative assessments were used to measure changes in problem-solving approaches. It discovers that they have an excellent understanding of solving the acid-base problems using the conceptual approach, with increasing: 13.0% to 60.9% and 43.4% to 56.5%. However, some mathematical issues appear if the conditions are related to more complex acid-base scenarios, such as those related to buffer and hydrolysis regions. It is shown that the percentage of the conceptual approach usage decreases or remains constant: 69.6% to 45.7% and 43.4%, respectively. This shows that the symbolic level in chemistry learning is also linked to mathematical skills. As a consequence, chemistry preservice teachers must have a strong mathematical basic skills to solve problems correctly. Further study is also recommended in other chemistry subjects to get a broader view.

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INTRODUCTION

The invisible interactions between acid and base species in solution occur at the submicroscopic level, whereas the pH value is the macroscopic phenomenon that is observable. Consequently, teachers in schools commonly determine the pH value using straightforward formulas to simplify interactions at the submicroscopic level, which promotes misconceptions. This is also reinforced by Salame, who states that students experience difficulties in understanding the concept of acid-base titration

because they are accustomed to solving problems using algorithmic calculations rather than a conceptual approach (Salame et al., 2022). It leads to misleading problem-solving. However, the conceptual approach considered the determination of the acid and base species in the solution, either in equilibrium conditions or not.

This approach facilitates a correct understanding of the pH value concept and other fundamental concepts in any general chemistry course (Awwalin & Nugroho, 2024). Therefore, it

plays a significant role in the chemistry learning process. Widarti et al. (2017) and Salame's (2022) studies found that the main obstacle for students and college students to determine pH value in acid-base titration is their inability to properly understand the determination of species at the submicroscopic level, which is represented at the third level.

A study conducted in one of the Chemistry Education Study Programs in East Java found that the usage of misleading problem-solving has occurred among college students. It shows that the misleading problem-solving has a long-term impact and has tendency to be transmitted (Widarti et al., 2017). However, the phenomenon appears to be similar among the preservice teachers in our study program. Therefore, we conducted the study in one of the mandatory courses related to their preparation to be a prospective chemistry teacher, which is Chemistry Learning for Senior High School.

Several studies using technology have developed visualization tools at the submicroscopic level to improve students' conceptual understanding using virtual experiments (Kartini et al., 2024; Tadesse, 2025) and the Augmented Reality (AR) approach (Rahayu et al., 2025; Tania & Sukarmin, 2025). From those studies, technology-based learning enables the discovery of the unseen part at the submicroscopic level to enhance students' conceptual understanding (Koehler et al., 2013). On the other hand, this study was conducted for preservice teachers, as pedagogical knowledge is also the objective in teaching experience.

Recently, several studies have nurtured the Technological, Pedagogical, and Content Knowledge (TPACK) framework in teacher training or education. Gonzalez & Bravo (2024) have reviewed the perception of teachers in secondary education of the use of TPACK in their classroom. The teachers expressed the importance of integrating technology in their classroom, which improved their teaching methods. It is emphasized by Nillson (2024) that integrating TPACK encourages teachers to develop their ideas in designing content knowledge in instructional strategies. It drives them to collaborate and reflect on the use of digital technologies linked to a topic.

According to these findings, the TPACK framework synthesizes the technological, pedagogical, and content knowledge in one framework that enables teachers to identify the most appropriate technology tools based on certain content and context during the learning activity. (Koehler et al., 2013).

In this way, technology within a pedagogical framework is beneficial to foster a comprehensive conceptual understanding in the learning process. In this study, we addressed the problem-solving issue in acid-base species determination for preservice chemistry teachers utilizing the TPACK framework. Furthermore, dig into the extent to which the preservice teachers engage in misleading problem-solving while determining acid-base species.

METHOD

Twenty-six college students of the Chemistry Education Study Program enrolled in the Chemistry Learning for Senior High School course at one of the educational universities in West Java, Indonesia. However, only twenty-three completely took the assessments. Those college students are in their third year and have already taken the General Chemistry course as a prerequisite. Their prior understanding of the acid-base topic is explored by doing assessments using structured questions in the pre-test using Google Forms.

To assess the final understanding, the paper-based post-test was taken at the end of the course. Since acid-base species determination is connected with several concepts, including acid-base, buffer, and salt hydrolysis, questions were constructed in a structured and purposeful strategy. Questions were taken from the exercise section in the general chemistry books or standardized exam questions, and thus considered valid already.

In this study, assessments were used to analyze the conceptual understandings before and after the course (Pahriah et al., 2025). A quantitative approach is employed by analyzing responses across several categories, as shown in Table 1. The categories are organized to provide information about students' misconceptions and learning gaps (Bhandurige & Suryawanshi, 2024).

Table 1. The categorization of preservice teachers' responses.

Category	Correct	Incorrect
Using a conceptual approach	1	2
Using a straightforward formula	3	4
Description		
1	Using a conceptual approach correctly.	
2	Using a conceptual approach incorrectly.	
3	Using a straightforward formula correctly.	
4	Using a straightforward formula incorrectly.	

Table 2. Learning design.

Stage	Process	Assignment	Assessment
Pre	Find the macroscopic, submicroscopic, and symbolic levels in a certain topic from general chemistry resources.	Multiple representation analysis	-
Course	<ol style="list-style-type: none"> 1. Deliver content using the multiple representation approach. 2. Incorporate technology in the presentation. 	Preparing an explanation on a certain topic using a multiple-representation approach.	Pre-test
Post	Measure the effect of the course.	-	Post-test

RESULTS AND DISCUSSION

Result

Problem-Solving Type in Responses.

The pre-test was conducted before the lesson in the Chemistry Learning for Senior High School using Google Form. Meanwhile, the post-test was taken on several related topics as the summative assessment. Questions focus on determining the acid-base species to investigate pH values in some regions, aiming to explore preservice teachers'

understanding. These regions are intentionally formed by the gradual addition of a strong base to a weak acid in an acid-base titration. The stoichiometric ratio between acid and base is equal. According to Table 3, the data presents four categories, with regions included as well. The understanding of the problems was also measured as correct and incorrect answers. All participants answered completely, except for two blank answers in the hydrolysis topics during the post-test: 95.5%.

Table 3. The percentage of preservice teachers' responses.

Category	Acid-base 1		Buffer		Hydrolysis		Acid-base 2	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1) Correct	13.0	60.9	52.2	34.8	30.4	39.1	39.1	47.8
2) Incorrect	47.8	21.7	17.4	10.9	13.0	8.7	4.3	8.7
Conceptual approach	60.8	82.6	69.6	45.7	43.4	43.4	43.4	56.5
3) Correct	8.7	13.0	4.3	32.6	8.7	4.3	8.7	17.4
4) Incorrect	30.4	4.3	26.1	21.7	47.8	47.8	47.8	26.1
Formula usage	39.1	17.3	30.4	54.3	56.5	52.1	56.5	43.5
Total answers	99.9	99.9	100	100	99.9	95.5	99.9	100

According to Table 3, categories 1) and 2) in the acid-base 1 region show that the percentage of conceptual approach usage to solve the problem is significantly increased from pre to post-test, followed by an increase in correct answers: 60.8% to 82.6%. This data is in line with categories 3) and 4), which show a decrease in the percentage of using the straightforward formula to solve the acid-base problems, 39.1% to 17.3%. Before the addition of a strong base, most preservice teachers

have a good conceptual understanding of determining pH values without other region steps.

The data from Table 3 in the buffer and hydrolysis regions indicate that only a few preservice teachers who use the straightforward formula in the pre-test change to the conceptual approach at the post-test, as shown by the decrease or remain constant in the percentage: 69.6% to 45.7% and 43.4%. respectively.

According to the responses, we found that if a

strong base is added to the system, some of them were confused about how to derive the equilibrium constant to get the pH value. Some of them, even though they have correctly determined the acid-base species, failed to calculate the pH value. At the end, they fall back on the straightforward formula, which leads them to misleading problem-solving. It shows that the preservice teachers give up on dealing with more complex acid-base species problems.

This finding is in line with previous research indicating that only a few students can understand the relationship between pH algorithms and the actual state of acid-base species in solution (Pratomo et al., 2025; Sheppard, 2006). In the hydrolysis region, the usage percentage of straightforward formulas has slightly decreased from 56.5% to 52.1%. We consider this because two blank responses occurred during the hydrolysis region.

As a result of the emphasis on the acid-base species determination, the correct answers in the acid-base 2 region increase: 43.4% to 56.5%. Here, we can conclude that even though the preservice teachers use the conceptual steps or the straightforward formula, both lead to the correct

answers. Since they are fully employed, the acid-base species determination in an equilibrium system leads to the correct answer. It shows the importance of the acid-base determination with a conceptual approach. Aside from that, there is also another finding: many preservice teachers use the straightforward formulas to time-saving in completing the limited-time assessments, which leads to a significant increase as well in the percentage of formula usage.

Misconceptions' Mapping.

According to Table 3, the higher the number of conceptual approach usage, the higher the correct answers, except in the buffer region category 1: 52.2% to 34.8%. This is proportional to the increase in correct responses obtained by applying the straightforward formula, which ranges from 30.4% to 54.3%. Consequently, we can state that applying straightforward formulas also produces the correct responses among preservice teachers. However, the misleading was unable to prevent the misconceptions. The misconceptions were discovered from the responses, as shown in Table 4. Due to the topics related to one another, we summarize all findings related to all regions.

Table 4. Misconceptions in all regions from the post-test responses.

Misconceptions	Number of responses
1) Mistaken in determining moles in the initial, reaction, and final step.	6
2) Improper formula usage.	2
3) Memorizing formulas without comprehending species' conditions at any region. Including in the acid-base 2 region: Incorrectly determining the species left, after the equivalent point is reached.	7
4) Mistakenly applied the formula in a certain region while calculating the pH value.	10
5) Confused about deriving the pH calculation from the equilibrium constant in the conceptual approach.	7

Misconception could also happen because of a lack of understanding of the prerequisite topic. It is pointed out in misconception point number 1 in Table 4. It must be clear that all preservice chemistry teachers master the mole concept before learning the acid-base concept. Points number 2 – 4 emerge from their inability to comprehend the overall concept of pH calculation in some regions, dependently into the acid-base species. Furthermore, Table 4 also identifies the misconceptions appeared from other related numerical skills, which is shown in point number 5. It is similar to point number 1 that deriving formulas is also part of the prerequisite concepts

that preservice chemistry teachers should have mastered due to its importance.

These findings show that the symbolic level in chemistry learning is also linked to numerical skills. As a consequence, chemistry preservice teachers must have a strong numeracy basis to solve problems effectively (Pratomo et al., 2025). It will be followed up on during the pedagogical strategies.

Discussions

Pedagogical strategies clarify the misconceptions.

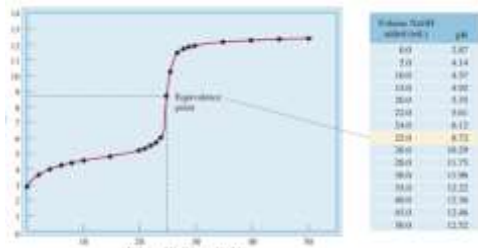
According to the result, many preservice teachers partially took the incorrect step in solving the problem. They fall back on the

straightforward formula when dealing with more complex acid-base species problems. Considering this, we design a pedagogical strategy using a multiple-representation approach to develop preservice students' understanding by explaining problems. Through this method, we would like to ensure a comprehensive understanding of the interconnection between macroscopic, sub-microscopic, and symbolic levels is going well.

The multiple representation analysis was assigned as the pre-course assignment. The aim of incorporating the multiple representation approach is to clarify the misleading of problem solving. One of the complex acid-base problems from the preservice teachers' responses is in the

titration process, including in the buffer and hydrolysis regions. During the course, all the preservice teachers are divided into groups of two with the responsibility to present one topic in every meeting. The presenter decided to choose the reaction between a weak acid and a strong base to address the inability to comprehend the overall concept of pH calculation in some regions, as shown in Table 5. They tried to construct the knowledge based on existing knowledge and offer the information required to create the new knowledge with minimal simplification of submicroscopic visualization (Permatasari et al., 2022; Treagust et al., 2003).

Table 5. Multiple Representation Analysis (Chang & Overby, 2011)

Description of Concept	Macroscopic Level	Sub-microscopic Level
We will consider three types of reaction: <ol style="list-style-type: none"> 1. Titrations involving a strong acid and a strong base 2. Titration involving a weak acid and a strong base 3. Titrations involving a strong acid and a weak base. 	<p>Weak Acid–Strong Base Titrations</p>  <p>pH profile of a weak acid–strong base titration. A 0.100 M NaOH solution is added from a burette to 25 mL of a 0.100 M CH₃COOH solution in an Erlenmeyer flask. Due to the hydrolysis of the salt formed, the pH at the equivalence point is >7. Therefore, at the equivalence point, when we only have sodium acetate present, the pH will be >7 as a result of the excess OH₂ ions formed. Note that this situation is analogous to the hydrolysis of sodium acetate (CH₃COONa).</p>	<p>Weak Acid–Strong Base Titrations</p> <p>Consider the neutralization reaction between acetic acid (a weak acid) and sodium hydroxide (a strong base):</p> $\text{CH}_3\text{COOH}(aq) + \text{NaOH}(aq) \rightarrow \text{CH}_3\text{COONa}(aq) + \text{H}_2\text{O}(l)$ <p>This equation can be simplified to:</p> $\text{CH}_3\text{COOH}(aq) + \text{OH}^-(aq) \rightarrow \text{CH}_3\text{COO}^-(aq) + \text{H}_2\text{O}(l)$ <p>The acetate ion undergoes hydrolysis as follows:</p> $\text{CH}_3\text{COO}^-(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{CH}_3\text{COOH}(aq) + \text{OH}^-(aq)$

During the course, the presenters use the general chemistry e-book as the main resource to ensure the accuracy of the content. They start from the graph of the titration, which is shown in Figure 1. a) at the macroscopic level, we can identify the data of the equivalent point and the change of the pH solution along the increase of sodium hydroxide volume. This phenomena then visualized by submicroscopic and transformed into a symbolic "language" with the picture under the graph. Emphasis on the submicroscopic level provides the preservice teachers with an idea of the conditions of the species in solution. This is crucial in helping them determine the moles of

species in each region. This step is important to clarify the misconception number 1 in Table 4.

In calculating pH values, to prevent the improper and mistaken use of the formula, the conceptual steps are needed. This step also strengthens the prerequisite concept. As shown in the results in Table 3, as much as 60.8% of the preservice teachers have a good understanding of the acid-base problem in one region, explained by their comprehensive understanding of how to determine the left species at the final stage, which is a weak acid. It drives them to calculate the pH correctly. Furthermore, the presenters have a good explanation for determining the species and

deriving the formula step by step, with the exception part highlighted in Figure 1. b) in the acid-base region.

Next addition of sodium hydroxide, due to the salt sodium acetate and acetic acid are left at the final stage, creating the buffer region in Figure 1) b. The calculation of pH applied the conceptual approach steps in solving the problems. Within this approach, the lecturer could strengthen the mole, the Henderson-Hasselbalch equation derivation, until calculating the pH value. So, they can apply a similar approach to solve the problems in

the buffer region in the classroom teaching situation. As long as the steps to answer remain constant, it will drive the correct answer frequently.

At the equivalent point, the presenters start the problem-solving from the species determination, and then derive the formula. But, because the condition at the final stage is that only salt is left. It means the presenters need to calculate the pH using the hydrolysis concept. Again, with the detailed step and exception highlighted, they explain the steps well, as shown in Figure 1) b. It occurs in the equivalent region.

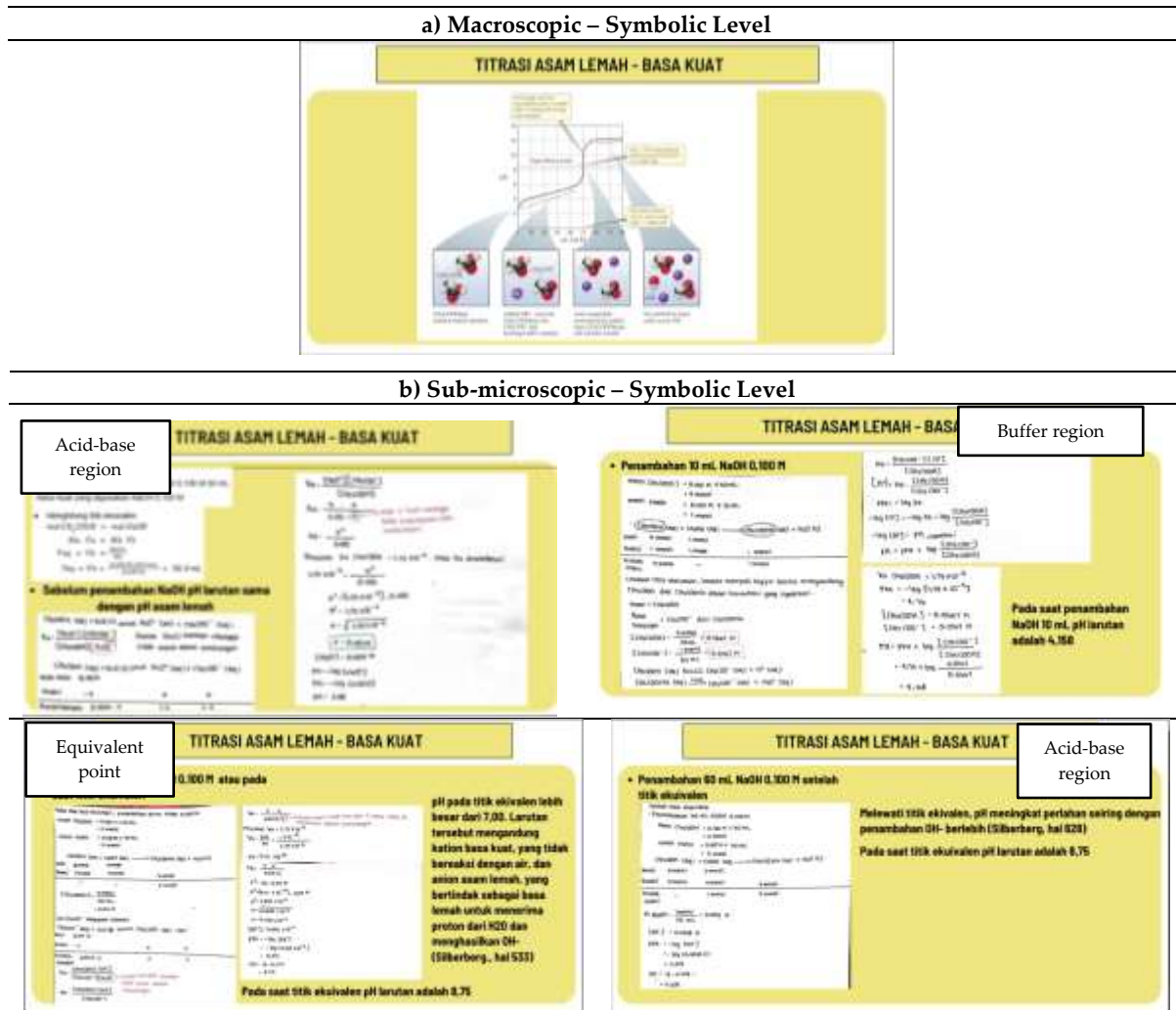


Figure 1. The multiple representations presented by preservice teachers consist of a) macroscopic – symbolic and b) submicroscopic – symbolic levels.

The last region is the acid-base region after the equivalent point. Here, due to the excess of sodium hydroxide at the final stage, the pH values are determined by the number of moles of hydroxide ions as a strong base. With this conceptual approach, preservice teachers are not necessary in memorizing or mistakenly apply formulas in different regions.

Apart from the presenter's excellent performance in delivering the topic, yet in explaining. Explaining could be challenging for preservice teachers to hit exactly what happens at the sub-microscopic level, using symbolic "language" to answer why the observable phenomenon (macroscopic level) occurs (Treagust et al., 2003). On the other hand, they

need as much experience in handling the real class conditions. The lecturer also needs to do an intervention to clarify the misconceptions and strengthen the prerequisite concepts.

Incorporating technology through the TPACK Framework.

A proper visualization of the submicroscopic level is a technological contribution in this era. Formerly, teachers struggled to guide students' understanding of the submicroscopic level, such as how to visualize the elements or atoms without causing many misconceptions. However, by using the visualization in Figure 1) a., the submicroscopic level represents the specific condition of species before, at, and after the equivalent points that represent every region in the acid-base problem. Technology constructs a better understanding of species determination of preservice teachers in the macroscopic phenomenon. When chemistry is combined with an appropriate technology, it can become an effective tool for enhancing audience comprehension (Duc Nguyen et al., 2026).

The use of Canva, as one of the types of learning technology that is commonly used among preservice teachers, helps teachers or other educators to be more effective in teaching activities. During the course, the presenters are not busy with writing activity on the board. With a manageable classroom flow, presenters are more engaged and interactive in answering the audience's responses and curiosity (Duc Nguyen et al., 2026).

Furthermore, the use of Canva enables the audience to dig more into the topic outside the classroom on their own (Ardyansyah & Rahayu, 2024). Thus, it not only serves as a learning tool during the learning process but also provides audiences with access to the material outside the classroom. Digital tools in learning are not only beneficial for the audience but also for the presenter, by providing them with the opportunity to collaborate remotely on one platform that is accessible anywhere and everywhere (Abareta & Prudente, 2025; Duc Nguyen et al., 2026). It enhances their professional development in adapting to future challenges (González & Bravo, 2023; Irawan et al., 2024; Tyas et al., 2025).

CONCLUSION

Most preservice teachers have a good conceptual understanding of determining pH

values in one region, which is in the acid-base region. Whereas in more complex acid-base species problems, in the buffer or hydrolysis regions, they fall back on using the straightforward formula. It leads to misleading problem-solving. The mapping misconceptions' data found that preservice teachers have challenges in the lack of prerequisite understanding concepts and in some mathematical issues. However, the study needs a larger sample size and should be broadened to other institutions to get a proper validation.

Clarifying the misleading problem-solving is not a simple thing. It needs to incorporate a suitable pedagogical approach and appropriate technology to drive a strong understanding. The learning was designed into pre-course, course, and post-course assignments, incorporating the multiple representation approach with the TPACK framework. Canva is a digital tool that is preferably used among presenters to engage the audience visually with an appropriate submicroscopic level visualization. It also helps teachers or other educators to be more effective in teaching activities. However, further study is needed in other challenging chemistry topics to get more proof that the approach is truly effective.

RECOMMENDATION

It is recommended to reinforce the prerequisite concepts, including mathematical skills related to the acid-base concept, to strengthen the preservice teachers' understanding.

Considering the effectiveness of technology incorporation during the lesson. It is also strongly recommended to incorporate an appropriate technology related to the other chemistry topics to prove the effectiveness of the approach.

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