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# Problem Solving in Chemistry: Example of Neutralization Titrations

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*Problem-solving is an important skill in analytical chemistry. This study aims to determine how chemistry teacher candidates use volumetric analysis problems and reveal the errors made. The research employs a descriptive survey model. The sample of the study consists of seven chemistry teacher candidates studying in the chemistry teaching programme. Questions requiring comparing the volume spent in NaOH and $HNO_3$, $H_2SO_4$, and $H_3PO_4$ titrations were asked within the scope of the study. The solution to the problem and explanations were recorded in a video. The results show that there are problems in determining the volume of NaOH. Many students wrote the titration reactions correctly, but there were problems with the effect values. It is noteworthy that those who made mistakes did not understand the first step of the problem. The students can prevent such mistakes with the help of a diagram summarizing the steps to be followed in the titration process.*

**KEYWORDS:** Analytical Chemistry, Neutralization Titration, Problem Solving

## INTRODUCTION

Chemistry is known as a difficult science subject among young people, and it is stated that it is difficult to make a career in science (Mujtaba, Sheldrake, & Reiss, 2020). Students perceive chemistry as quite boring, difficult, and challenging. Some issues of chemistry, such as visualizing the structure of the atom and how chemical bonds occur, are thought to be difficult to understand by nature (Ruschenpohler & Markic, 2020). Activities related to chemistry will allow students to realize that chemistry is understandable and applicable (Mujtaba et al., 2020). Analytical chemistry and qualitative-quantitative analysis practices have an important place in chemistry education. How to

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obtain the amount of a specific substance in a sample by weighing the precipitated portion or measuring the volume of solution should be taught in analytical chemistry. Gravimetric analysis and volumetric analysis are still thought to form the basis in analytical chemistry (Arikawa, 2001). Colour change and precipitation reactions are widely used in the recognition of substances while conducting qualitative analysis experiments (Berry, 2015). Determination, separation, and quantification of the components that constitute an example fall within the subject area of analytical chemistry. The quantitative analysis determines which chemicals a sample contains and how much of these chemicals are numerically present (Skoog, 2005). The student who will perform an analysis should master the basic knowledge of traditional quantitative analysis laboratory chemical analysis (Zimmerman & Jacobsen, 1996). Students should learn how to use an example given to them, how to determine cations in each group, whether or not they are present, perform laboratory applications involving changes in colour and/or appearance, and reach results based on both theory and reactions with qualitative analysis. Students should combine theory with experimental work (Guerrero, Jaramillo, & Meneses, 2016). Within the scope of analytical chemistry course, students make qualitative and quantitative analysis of a sample. While doing this, they use the procedures of gravimetry, titrimetric chemical methods. They should benefit from the skills learned in analytical chemistry such as weighing, measuring volume, calculating mass, solving problems, and calculating concentration (Shekhovtsova, 2018). Laboratory practice has an important place in shaping analytical chemistry knowledge. In the laboratory, students try to get to know the practical aspects of analytical chemistry and can better understand what they are listening to in class. For this reason, laboratory practices should be designed in such a way as to ensure the follow-up of written procedures, learn how to record data, and teach how to perform operations correctly (Gros, 2019).

Operations such as operations in volumetric analysis, known as a series of operations, calculations, and determining the amount of matter require problem-solving and higher order thinking skills due to mathematical calculations. Information structure is the strongest predictor of problem-solving performance. For this, the information needs to be stored from short-term memory to long-term memory. Individuals can easily remember more information to help solve problems if new information is integrated with previous information (Lopez, Shavelson, Nandagopal, Szu, & Penn, 2014). The combination of our knowledge and skills base contributes to solving a problem successfully. Our knowledge base is about which category of information belongs in our minds. The skill base includes the ability to read, perform mathematical manipulations, check the results, check that no information is overlooked, and check whether the problem is solved. Other elements include analysing a problem and planning the possible route to the solution. Skills may be domain-specific (e.g., equating an equation) or more general (e.g., using numbers appropriately) (Lyle & Robinson, 2001). The information obtained is used to associate the newly encountered information with the information existing in our minds according to the cognitive theory of learning (Newell & Simon, 1972). The information is used to determine the purpose of the problem and to interpret the information when a problem is encountered. When a problem is solved, we not only have a solution to that problem, but we also have a new and revised knowledge base (Lyle & Robinson, 2001). Problem-solving teaching has shown that knowledge is better understood, stored, and can be transferred when created by the student (Norman & Schmidt, 1992). Different problem-solving activities should be implemented for a student to solve problems fluently and error-free. Both skills and knowledge base are reinforced in practice in this way (Taconis, Ferguson-Hessler, & Broekkamp, 2001). Problem solving and problem-based learning practices allow students to explore their knowledge and learning outcomes, thus improving their metacognitive abilities. Students discover their ability to understand concepts, solve problems, and apply knowledge to problems (Awaliah & Ikhsan, 2021). Today, generation Z individuals should be considered while developing course contents and applications. These individuals are more visual and tactile than those who learn by listening, and they also expect feedback. These characteristics of students should also be taken into account in the content of analytical chemistry. For this, useful and at the same time entertaining tools should be used to solve the complex techniques of analytical chemistry and to highlight its confusing points. While the tools encourage comprehensive study, they should enable active participation with competition and game features, encourage solving questions, checking information with friends, and encouraging group work (Miranda-Castro & De-Los-Santos-Álvarez, 2020).

## Problem-Solving in Chemistry

Problem-solving steps begin with understanding the problem. The second step is the design of the plan, the third step is the implementation of the plan, and the fourth and final step is the evaluation of the result (Polya, 1957). Sometimes the number of steps may increase when problem-solving is adapted to physics, chemistry, and mathematics. But basically, these four steps are followed. The problem needs to be understood qualitatively well. Students should be given the opportunity to think aloud when solving a problem and derive non-mathematical procedures for problems instead of giving numerical procedures to achieve this. Problem sentences should include statements that will enable students to think about the problem. The students must create the procedures, that is, the steps to be used when solving the problem in this way.

Plenty of practice should be done and more questions should be solved for the procedures developed for the basic problems to have an algorithmic place in the mind (Heyworth, 1998).

Problem-solving in chemistry is taught through textbooks or examples of problems and courses in which their solutions are explained. It causes to focus only on the steps to be followed to solve the problem instead of the knowledge required to understand such teaching problem and the skills (cognitive strategies) to be used to solve it (Lyle & Robinson, 2001). Experiments include problem-solving teaching in science and mathematics courses from primary school to university (Glass, 1976). Teachers' explanations or teaching good problem-solving techniques while solving problems are not very valuable for students to be better problem-solvers (Hayes, 1981). The important point in problem-solving is not that the students solve the questions with ratios, but that they can explain what the ratios mean (J. Cohen et al., 2000). Students usually memorize formulas or equations to solve the problem and make calculations unless they are asked to explain or interpret a situation (Lawson, Lawson, & Lawson, 1984). Teachers should examine the student's use of concepts, ratios, and symbols, as well as evaluate numerical answers to understand whether a student has a meaningful problem-solving ability (J. Cohen et al., 2000).

Traditional teaching creates learning characterised by a superficial and cursory, high level of memorization. Students remember very little of what they have learned and have difficulty in applying this little information that they do not forget (Saint-Jean, 1994). We often underestimate the way to prepare students for thinking, and as a result, we cannot fully contribute to students' intellectual development (Christensen, Garvin, & Sweet, 1991). The importance of conceptual understanding emerges when we examine the cognitive factors that are effective in students solving quantitative problems. Conceptual understanding ensures good recognition of the problem and the efficient use of cognitive strategies to be used in the solution process. It is necessary to first examine the processes followed, to identify the deficiencies of these processes, and then to derive teaching approaches that will help accordingly to develop problem-solving skills (Heyworth, 1998).

Chemistry teachers and researchers state that students have difficulty and anxiety in making calculations in the volumetric analysis (Duncan & Johnstone, 1973; Johnstone, Morrison, & Sharp, 1971). It is thought that the reason for the difficulties experienced by the students while making calculation problems is due to the task components in the nature of this process and it is based on its structure in the volumetric analysis (Wheeler & Kass, 1977). The problems experienced by the students in problem-solving are identified and appropriate teaching strategies can be focused on to overcome these difficulties if the difficulties inherent in the volumetric analysis task are identified. Determining and isolating the sources of difficulties experienced by students also helps to understand how these difficulties affect their abilities and why they solve volumetric analysis problems (Anamuah-Mensah, 1981). Students also experience difficulties with concepts in volumetric analysis. The concept of molarity, for example. The concept should be concretely associated with coloured substances such as concentrated and diluted orange juice instead of using colourless acid and base solutions while explaining the concept of molarity in order to ensure the conceptual understanding of the student (Heyworth, 1998). Since chemistry is a conceptually difficult field to understand, students experience difficulties while learning the subjects. Chemistry educators should be aware of these challenges and enable students to overcome them by taking appropriate precautions (Gegios, Salta, & Koinis, 2017). One of the important competencies in chemistry education is the ability to solve chemical problems. For students, problem solving in chemistry learning and teaching emerges as an important point of difficulty (Kimberlin & Yezierski, 2016). High school and university students have difficulties in solving quantitative chemistry problems (Nakhleh, 1992). The difficulties that students experience while solving problems in chemistry are due to their inadequacy in mathematics (Dahsah & Coll, 2008) and their focus on algorithms instead of logic while calculating (Fach, Boer, & Parchmann, 2007). Students tend to solve problems with different algorithmic techniques without using scientific concepts in solving quantitative problems (Gabel, 1993). Students have difficulties in applying the algorithms they use in traditional problem solving to new problems (Cracolice, Deming, & Ehlell, 2008). The difficulties experienced in solving volumetric analysis problems have been explained in detail in the literature. When students encounter a problem in chemistry, they try to solve the problem directly by using a formula or by trying the algorithms they used to solve a problem before they realize the chemistry-related concepts in the problem and try to find the right answer. The use of problem-solving steps and the errors made in the process of solving the volumetric analysis problems of chemistry teacher candidates were examined in this study.

## Review of Related Literature

In his study, Bilgin (2005) examined the effect of problem-solving approach supported by cooperative learning on the quantitative problem-solving success of primary school teacher candidates in chemistry. The research was carried out with 150 classroom teacher candidates. In the research, there are the first group in which traditional problem-solving method is applied, the second group in which Polya's problem solving method is applied, and the third group in which Polya's problem solving method is applied with cooperative learning. As a result of the research, it has been determined that the problem-solving approach supported by cooperative learning is more effective in solving the quantitative problems of chemistry course. The problem-solving steps used to solve a problem are the same for all problems or cannot be said to be used. However, the solution of many problems proceeds as follows: understanding the problem, planning for the solution of the problem, and evaluation steps.

Lopez et al. (2014) examined university students' level of solving organic problems in their study and investigated its relationship with various variables. The research was conducted with 90 university students. Structure and Bonding, Stereochemistry, Alkyl Halide Reactions, Reactions of Alkenes learning areas were determined for organic chemistry. Problem sets related to the determined organic chemistry learning areas were applied to the students. Data were collected through problem sets and concept maps. The analysis of the data was carried out by scoring and coding the applied problem sets and concept maps. Problem sets were scored as correct (1 point), incorrect (0 points), and partially correct (0.5 points). Concept maps were scored as incorrect scientifically unrelated (0 points), partially incorrect (1 point), scientifically inadequate but technically correct (2 points), scientifically and technically correct (3 points) according to the correctness of the proposition. As a result of the research, it was determined that concept map is an important predictor of problem-solving performance. Knowledge structures revealed by concept maps are a strong predictor of problem-solving performance. To improve the problem-solving performance of students, their knowledge structures should be developed first. The focus should be on quantitative and qualitative problem-solving skills. All the contents learned in chemistry are related to each other.

Shadreck and Enunuwe (2018) conducted a study to determine the difficulties that high school students experience while solving problems in chemistry. In the research conducted with 525 high school students, a quasi-experimental design with experimental control group was used. While traditional teaching was carried out in the control group, problem solving teaching was carried out in the experimental group. As a result of the research, the difficulties encountered by students while solving stoichiometry problems; inability to understand the concept of mole, to balance chemical equations, and to establish stoichiometric relationships.

In their study, Ijirana and Supriadi (2018) aimed to define students' metacognitive skill profiles, to identify the characteristics of chemistry students and to reveal the problems they experience in problem solving. Knowing students' metacognitive skill profiles allows teachers to use appropriate teaching methods to reduce students' difficulties. Metacognitive skills are explained with problem solving steps. These skills are planning, monitoring and evaluating. In the study, students were asked to solve chemistry questions. Solution steps were examined one by one according to metacognitive skills. Findings revealed that students only use planning skills while solving problems, and they never use monitoring and evaluating skills.

Salame, Casino, and Hodges (2020) revealed the difficulties faced by 184 university students while learning organic chemistry synthesis. As a result of the research, it was determined that the students focused on memorizing a rule while solving organic chemistry problems, so their conceptual understanding of the subjects was weak. In addition, they state that in solving organic chemistry synthesis problems, the teaching system based on memorization and rote inhibits the learning process and the development of problem-solving skills.

Lopez-Jimenez, Gil-Duque, and Garces-Gamez (2021) examined the application of Polya's proposed problem-solving steps in physics course. The experiment was carried out with 40 students in the control group. In the experimental group, the subjects were explained theoretically and mathematically, then information was given about the problem-solving steps, and the students solved the problems given to them by including these steps in the solution of the problem in written and verbal form. In the control group, the subjects were explained theoretically and mathematically, and the students freely solved the problems given to them without being bound by a rule. As a result of the research, it was revealed that the students in the experimental group who practiced problem solving solved the problems more satisfactorily. It was determined that the basic steps suggested for the problem were not followed in the control group. An increase was observed in the problem-solving capacity of the experimental group. Although they had difficulty in applying at first, they realized the importance of using problem-solving steps when they saw the benefits in the learning process.

Savitri, Amalia, Prabowo, Rahmadani, and Kholidah (2021), in their study to examine students' scientific literacy and problem-solving skills, determined that the digital application of science made a significant and positive contribution to problem definition, problem-solving planning, problem-solving and controlling all stages.

In their research, Freitas and Campos (2021) developed a scientific platform for the application of problem solving in the teaching and learning of chemistry. On this platform, teachers are given information about problem solving. In this way, teachers have access to current publications and new applications. It is also a platform where ideas on problem solving in the field of chemistry are shared and discussed and contribute to developments. Teachers expressed positive opinions in the interviews and stated that they would contribute to the teachers' pedagogical practices.

## The Aim of the Study

Experiments include teaching problem-solving in science and chemistry. Problem-solving takes place in four steps: understanding the problem, designing the plan, implementing the plan, and evaluating the result. Polya's problem-solving steps are like the steps to be followed in solving volumetric analysis problems. This study aims to define the process of solving the volumetric analysis problems of chemistry teacher candidates, to determine to what extent they use the steps of problem-solving, and to determine the errors made. Answers to the following questions were sought in the research:

Q1. To what extent are the problem-solving steps used by chemistry teacher candidates when solving volumetric analysis problems?

Q2. What are the errors made by teacher candidates in solving volumetric analysis problems?

## Research Methodology

The research model used is a descriptive survey model. It is carried out to identify, compare, classify, analyse, and interpret the groups and events that make up the research fields. Descriptive scanning aims to explain the data about the related variables (L. Cohen, Manion, & Morrison, 2007). A purposeful convenience sampling method was used in the study. The sample of the study consists of seven chemistry teacher candidates studying in the chemistry teaching programme of a state university. 85.71% (N:6) of the sample group were female and 14.29% (N:1) were male. Six of the teacher candidates were in the sixth semester while 1 was in the eighth semester. The age of the sample group varies between 21 and 22 years.

## Data Collection Tools

The data of the study were collected with written responses including problem-solving and semi-structured interviews. Teacher candidates were asked an open-ended question asking to compare the volume spent in NaOH and $HNO_3$, $H_2SO_4$, and $H_3PO_4$ titrations (Figure 1). Papers containing problem solutions were taken as written responses. The solution to the problem and explanations were recorded in a video and transcribed.

### Semi-Structured Interviews

Semi-structured interviews were conducted with teacher candidates in this study to reveal what individuals think, feel, perceive, and their attitudes about

**Name:**
**Date:**

**1.** The 0.105 M NaOH solution is put into a 50 mL burette. It is wanted to determine the amount of $HNO_3$ solution put into the erlenmeyer flask. The final value read from the burette for NaOH is 46.6 mL. Accordingly, calculate the amount of $HNO_3$ in the sample given to you.

If it is desired to determine the amount of $H_2SO_4$ and $H_3PO_4$ acid solutions with the same NaOH solution, compare the spent NaOH volumes with that in the $HNO_3$ sample.

**Titration equation:**

| **Acide** | **The amount of NaOH spent** |
|---|---|
| $HNO_3$ | |
| $H_2SO_4$ | |
| $H_3PO_4$ | |

**Figure 1. Question Text Used in the Study**

a subject (Yildirim & Simsek, 2013). The semi-structured interview was carried out to examine in-depth the problems encountered by teacher candidates on topics such as reading volume, recording data, and calculating. The questions were prepared before the interview, but additional questions can be asked to obtain more detailed data about the subject according to the course of the interview in the semi-structured interview. Semi-structured interviews were recorded with a video recorder.

## Application Process

Chemistry teacher candidates take 3 lessons per week of analytical chemistry and three lessons per week of analytical chemistry laboratory courses. Qualitative and quantitative analysis methods are explained within the scope of the courses and their applications were carried out in the laboratory. Teacher candidates were asked a question to compare the volume spent in NaOH and $HNO_3$, $H_2SO_4$, and $H_3PO_4$ titrations, and the solution of the problem and explanations were recorded in a video. The interviews with each student lasted approximately 25-30 minutes.

## Data Analysis

The data obtained from the semi-structured interview video recordings were transcribed. Content analysis was used to analyse the interviews. The data collected in content analysis is based on the creation of certain concepts and categories (Yildirim & Simsek, 2013). Consistency analysis was performed to determine the reliability of the interview analysis. The level of consistency between categories should be 80% or more (Miles & Huberman, 1994). The percentage of agreement was calculated as 98% because of the examination of the interview data by two experts, accordingly.

## Results of the Study

The first category determined according to content analysis is to be able to show the volume on the burette, to determine the NaOH volume, to know the effect value, to write the titration reaction, to convert the titration equation and to compare the volumes spent for $H_2SO_4$ and $H_3PO_4$. The categories determined by Polya's problem-solving steps, and the analysis of the interviews are given in Table 1.

**Table 1**

**Results of the Categories Determined According to Polya's Problem-Solving Steps.**

| Polya's Problem Solving Steps | Categories | Criterion | Students |
|---|---|---|---|
| Understand the problem | Show the volume on the burette | T | S1, S2, S3, S4, S5, S6, S7 |
| | | F | - |
| | Determine the NaOH volume | T | S5 |
| | | F | S1, S2, S3, S4, S6, S7 |
| Design the plan | Know the effect value | T | S3, S4, S5, S6, S7 |
| | | F | S1, S2 |
| | Write the titration reaction | T | S1, S3, S4, S5, S6, S7 |
| | | F | S2 |
| Implementation of the plan | Ability to convert the titration equation | T | S3, S4, S5, S6, S7 |
| | | F | S1, S2 |

*Continued on next page*

*Table 1 continued*

| | | | |
|---|---|---|---|
| Evaluation of the result | Comparing volumes for $H_2SO_4$ and $H_3PO_4$ | T | S3, S4, S5, S6, S7 |
| | | F | S1, S2 |
| | | T | S3, S4, S5, S6, S7 |
| | | F | S1, S2 |

## Polya's Problem Solving Steps and Findings Related to "Understand the Problem"

The first of Polya's problem-solving steps is to understand the problem. It is necessary to show the volume on the burette and determine the NaOH volume, accordingly. The first category is to be able to show the volume on the burette. All teacher candidates performed the demonstration process correctly here (Figure 2 and 3).

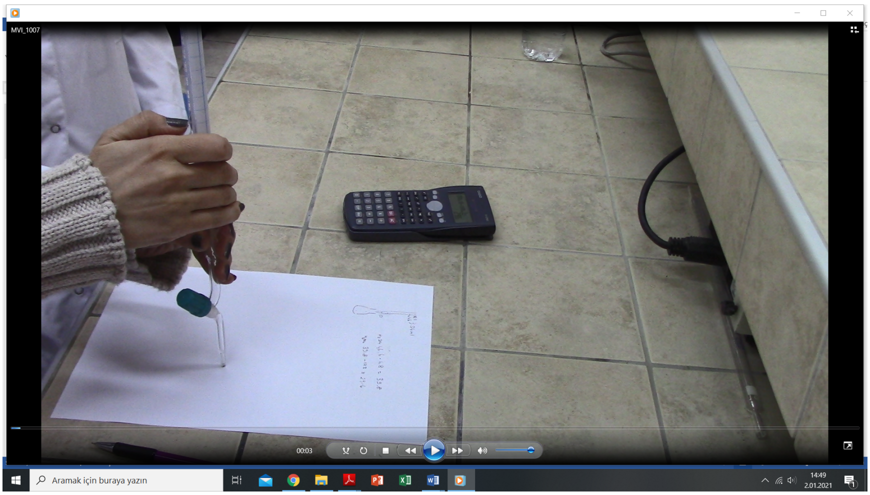


**Figure 2. Examples of Student Demonstrations**

One teacher candidate did it correctly and six teacher candidates made mistakes in determining the NaOH volume, which is the second category. The explanations of the teacher candidate that did it correctly was: *If I think about the amount spent from the burette, I can decide how much the volume will be. I think I make it easier by drawing, the volume is 46.6 ml, accordingly (S5).*

The explanations of those who made mistakes were: *If all is 50 ml and 46.6 ml is spent, we need to subtract it from 50 (S1). It needs to be subtracted from 50 ml*

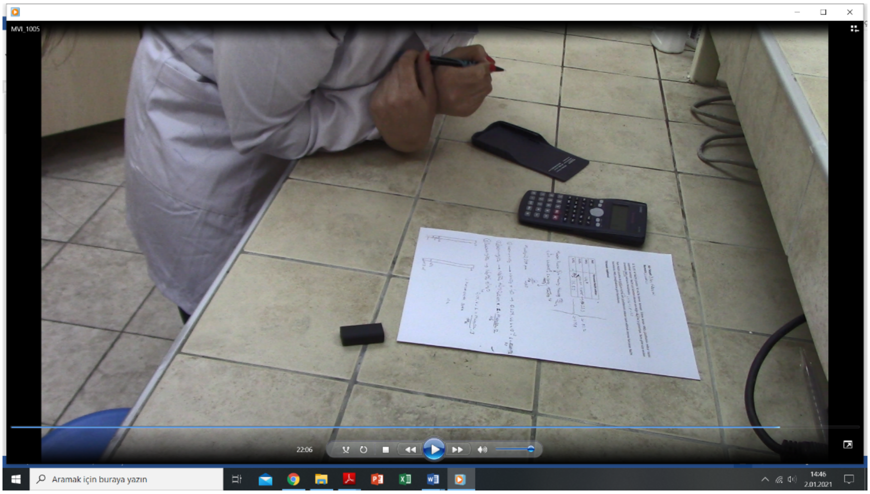

**Figure 3. Examples of Student Demonstrations**

*to find the volume spent from the burette (S2). 46.6 will be subtracted from 50 lastly (S3). The volume of NaOH spent is 50-46.6 (S4). I start by calculating the volume of NaOH spent. Since the burette is 50ml, I find it as 50-46.6 (S6). The volume spent for the first part is 50 ml and the volume of* $HNO_3$ *is 46.6 ml. Then the student reads the question again and realizes that he/she has written the volumes incorrectly. Then he/she cannot decide whether the volume will be 46.6 or 50-46.6 (S7).*

## Polya's Problem Solving Steps and Findings Related to "Design the Plan"

The second step of problem-solving is the design of the plan. It is necessary that in this step the titration reaction be written first and then to know the effect value. It was determined that there were 6 correct and 1 incorrect response in the category of writing the titration reaction.

The explanations of those who did it correctly are: *When acid and base react in the titration reaction, salt and water are formed, where salt is again involved, but since their value is -2, I wrote the formula of salt as* $Na_2SO_4$*, if I consider other reactions in* $H_3PO_4$ *titration reaction, I write that the salt formed because* $PO_4$ *has a value of -3 according to the reaction is* $Na_3PO_4$ *(S1).*

*According to the titration reaction, the reaction of acid and base will yield salt and water. The value of* $SO_4$ *is -2, the salt formed in the reaction when crossed is* $Na_2SO_4$*. Can I think about it for equalizing? I can if I write 2. The value of* $PO_4$ *in the* $H_3PO_4$ *reaction is -3 and the resulting salt will be* $Na_3PO_4$ *(S3).*

*When the base reacts with the acid, water, and salt is formed, which is as follows ($NaNO_3$). I'm going to form water again in $H_2SO_4$, so that leaves $SO_4$ 2-, I mixed it with Na, it's a little Na +1, so I don't know how to combine it. In $H_3PO_4$, I will write 3 here and form the salt and write water (S4).*

*In $HNO_3$, the salt formed because of $NO_3$-1 and Na +1 is $NaNO_3$ and water is formed. In $H_2SO_4$, Na is +1, $SO_4$ is -2, $Na_2SO_4$ salt is formed, so if I write 2 at the beginning to equalize it, it's equal. Since $PO_4$ is -3 and Na is +1, the salt will be $Na_3PO_4$ and there is water, I equate the reaction by writing 3 (S5).*

*Then the reaction of acid and base forms salt and water, sodium nitrate, and water, let's see if the reaction is equivalent, and my reaction is equivalent. In $H_2SO_4$, sodium sulphate will be $Na_2SO_4$, $SO_4$ has -2 and water will form again. Write 2 here and it's going to be an equal reaction. In this reaction $H_3PO_4$, $Na_3PO_4$ and water will form, and I'll equate it equate by writing 3 (S6).*

*The first reaction will consist of sodium nitrate salt and water. Sodium + sulphate -2, 2 in sulphate will be here and sodium sulphate $Na_2SO_4$ salt and water will form and will be equivalent to 2 in the second reaction. $Na_3PO_4$ is formed due to -3 in $PO_4$, and water is formed, it will be equal when 3 is brought here for the third titration (S7).*

The false expression was: *salt and water are formed, and $NaNO_3$ is formed here. Sodium sulphate salt is formed for $H_2SO_4$, right! $SO_4$ 2- is correct; I wrote the salt wrong. Sodium phosphate salt is formed, but I cannot equalize. I cannot be sure of the correctness of the reaction (S2).*

There are 5 correct and 2 incorrect responses in the category of knowing the effect value. The explanations of those who made mistakes are: *Mathematically I can tell the effect value, but I can't tell the chemical logic (S1), the effect value is taken according to the hydrogen numbers, so I took 1 here (S2).*

The explanations of those who did it correctly are: *The effect value is the number of $H^+$ or OH- given to water, the effect value is 1 (S3). It gives 1 hydroxide ion to the water, so it is 1 (S4). The effect value gives one hydroxide ion when NaOH ionizes, so it is 1. $HNO_3$ is also 1, so it gives a hydrogen ion (S5). The effect value was the number of hydrogen and hydroxide given by acid or base, and the number of ions in salt (S6). The effect value is 1 due to the hydroxide given by NaOH to the environment. The effect value of $HNO_3$ is 1 because it gives 1 $H^+$ to the environment (S7).*

### Polya's Problem Solving Steps and Findings Related to "Implementation of the Plan"

The third step of problem-solving is the implementation of the plan. This step is met by the ability to convert the titration equation in a neutralization reaction question. There are 5 correct and 2 incorrect responses when the category of converting the titration equation is examined.

The explanations of those who did it correctly are:

*We will equalize the equivalent grams of acid-base and open the molarity because it requires the amount (S3).*

*The point where the titration ends is the point where the equivalent grams are equal, so I wrote them by equalizing them, I moved to the mass of what is required to be in the equation (S4).*

*At the turning point, the equivalent grams are equal, so we write the equation like this, we switch to molarity, and then we switch from here to the required mass (S5).*

*We had a formula; we find it in proportion to the effect value of molarity. The equivalent number of grams is acid, and we write the base, and we open my formula, then we open the molarity, and we move from mole to mass (S6).*

*Looking at the question, it means grams. I will switch from molarity to mole, and from there to mass (S7).*

The explanations of those who made mistakes are as follows:

*After the candidate wrote the titration equation, he/she did not have any problem in switching to what was requested in the question, namely $HNO_3$ amount, I wrote the equation incorrectly, yes, I need to correct it. Shouldn't the volume of acid be given? I think there is some incomplete data in the question. I think more information should be given (S1).*

*There is something wrong with the question since molarity is required. Isn't that what we wrote in the lesson in the experiment (S2).*

## Polya's Problem Solving Steps and Findings Related to "Evaluation of the Result"

The last step of problem-solving is the evaluation of the result. This step is associated with comparing volumes. There are 5 correct and 2 incorrect responses in the category of comparing volumes for $HNO_3$, $H_2SO_4$, and $H_3PO_4$.

The explanations of those who did it correctly are:

*According to the titration reaction, it doubles the mole, so I'm confused whether the NaOH volume will decrease by half or double. Later, he/she thought aloud and said that the volume of NaOH spent would double. Since the amount of H+ increases, the amount to be used increases accordingly. $H_3PO_4$ increases by 3 times the volume spent here (S3).*

*Since the NaOH volume spent is $H_2SO_4$ polyprotic acid, it will give two H ions to the environment; therefore, twice as much volume is spent. In $H_3PO_4$, the volume spent will be 3 times as much, the H ion given to the environment is more (S4).*

*We can say it's twice the amount to be spent. Because it will be higher because the number of ionizing hydrogens is higher. Since* $H_2SO_4$ *is a diprotic acid, its effect value is 2, and it can be twice as much. We can say about 3 times for* $H_3PO_4$ *(S5).*

*The amount spent should be twice the amount of the reaction. It is used twice as much because it is diprotic because it ionizes in water. It is spent 3 times as much according to* $H_3PO_4$ *reaction (S6).*

*It is spent twice as much since the effect value is 2. The other should be 3 times as much (S7).*

The explanations of those who made mistakes are as follows:

*Since* $H_2SO_4$ *doubles its effect value, this situation passes to the other side as a division and is spent half as much. Since the NaOH volume spent for* $H_3PO_4$ *has an effect value of 3, it is spent as little as one third (S1).*

*The volume spent for NaOH will be less,* $H_2SO_4$ *has more hydrogen since they will react less than NaOH. Likewise,* $H_3PO_4$ *is spent even less (S2).*

## Discussion and Conclusions

This study aims to define the process of solving the volumetric analysis problems of chemistry teacher candidates, to determine to what extent they use the steps of problem-solving, and to determine the errors made. A question requiring comparing the volume spent in NaOH and $HNO_3$, $H_2SO_4$, and $H_3PO_4$ titrations was asked within the scope of the study. Then, the solution to the problem and explanations were recorded in a video. The categories of being able to show the volume on the burette, to determine the NaOH volume, to know the effect value, to write the titration reaction, to convert the titration equation and to compare the volumes for $H_2SO_4$ and $H_3PO_4$ have been determined. The categories determined by the analysis of the interviews were met as follows when Polya's problem-solving steps were taken into consideration:

The first step of Polya's problem-solving was to understand the problem. The individuals who understand the problem in solving the problem related to neutralization titrations are expected to understand the purpose of the problem and the data necessary to solve the problem. It is necessary to show the volume on the burette and determine the NaOH volume, accordingly. They are experiencing problems in understanding the problem. There are problems in determining the volume of NaOH from the statements in the question. The individuals tried to remember and decide on what was told in the analytical chemistry course and what was done in the experiments. The second step of problem-solving was design of the plan. Here, a plan should be made according to the component that individuals want to find based on what is necessary for the solution of the problem. What will be found, which unit will be used, should be kept in mind at all times. It is necessary for this step to write the titration reaction first and to know the effect value. In this step, the majority of the process of writing the titration reaction wrote the reaction correctly, and there are problems in the effect value. Here, it was noticed that there were problems in making sense of chemistry. The third step of problem-solving was the implementation of the plan. It is the implementation of the plan designed for the solution of the problem. This step is met by the ability to convert the titration equation in a neutralization reaction question. Those who have problems in converting the titration equation are the ones who have difficulty in understanding the problem. Those who misunderstood the problem also made mistakes in the application process. The last step of problem-solving was the evaluation of the result. Here, the whole process is checked and reviewed from beginning to end. The individual should compare the volumes spent in evaluating the result in quantitative analysis questions. The category of comparing volumes for $HNO_3$, $H_2SO_4$, and $H_3PO_4$ corresponds to this step. It is noteworthy that those who made mistakes did not understand the first step of the problem. Mistakes made can be prevented with a diagram summarizing the steps to be followed by the students in titration calculations. The steps in this diagram are determining the analyte-titrate, checking the units, writing the titration equation, using the stoichiometric ratios (explaining the effect value), calculating the required, checking the unit. The steps in this diagram are similar to the evaluation criteria of the volumetric analysis. It was determined that students who follow the problem-solving network have increased confidence and skills in calculations (Waddling, 1983).

The second aim of the study was to examine the mistakes made by pre-service teachers in the problem-solving process. Teacher candidates thought that the total volume of the burette should be excluded from the total in the study. The biggest problem of today's teaching process is that students cannot add new information they learn in lessons or experiments to their knowledge base. Teachers should use different teaching techniques to ensure that students can perform this process. For example, it was determined that problem-solving techniques were more effective in teaching the subject of stoichiometry than traditional teaching (Sunday, Ibemenji, & Alamina, 2019). Students should first be provided with their understanding of the conceptual basis of a topic such as stoichiometry and then problem-solving should be taught by algorithmic means in the process of problem-solving in chemistry. There are difficulties in translating the words into mathematical equations. Students should be able to translate the contents of the problem text into chemical and mathematical equations before solving the problem (Hafsah, Hasmin, Ismail, Jusoff, & Yin, 2014). The information is used to determine the purpose of the problem and to interpret the information when a problem is encountered. When a problem is solved, we not only have a solution to that problem, but we also have a new and revised knowledge base (Lyle & Robinson, 2001). Difficulties in solving problems in chemistry subjects such as stoichiometry arise from problems in conceptual understanding (Chandrasegaran, Treagust, Waldrip, & Chandrasegaran, 2009). Students should pay attention to conceptual understanding while studying and learning chemistry, and teachers should pay attention to conceptual understanding when teaching chemistry (Derman, Kayacan, & Kocak, 2016).

Another finding of the research was that there were mistakes related to concepts. Here, volumetric analysis emerged in determining the effect value in problem-solving. One of the students who made a mistake about the effect value could not explain that he knew mathematically but did not know its chemical logic, and the other said that it was determined according to the number of hydrogen and failed to explain it. Students experience difficulties with concepts in volumetric analysis. Molarity, for example, is the most basic concept. The definition of molarity and the mol/litre formula are not understandable for the student. Therefore, ensuring that this concept is understandable is the first thing to do. A relationship should be established with daily life in order to embody the concepts. The second important thing is that the problem needs to be understood qualitatively well. Students should be given the opportunity to think aloud when solving a problem and derive non-mathematical procedures for problems instead of giving numerical procedures to achieve this (Heyworth, 1998). It should be ensured that the students prepare the solutions they will use themselves in order to comprehend the purpose of chemistry experiments. They will understand why the actual concentration of NaOH used in the neutralization experiment should be standardized when it is lower in this way (Mcmills, Nyasulu, & Barlag, 2012). Students' working habits, reading skills, studying problems, and problems assigned as homework were found to be effective in learning volumetric analysis (Alam, Oke, & Orimogunje, 2010). Information that is forgotten or confused after time passes through the experiments should be checked with the assignments given at certain time intervals and the permanence of the information should be ensured. The information obtained is used to associate the newly encountered information with the information existing in our minds according to the cognitive theory of learning (Newell & Simon, 1972).

Chemistry teacher candidates made mistakes in writing and transforming the titration equation in the research. Those who made mistakes in converting the equation of titration according to what is required in the question tried to remember how they had done it in the course and in the experiment or claimed that incomplete information was given. As a teacher, we should help the students develop a systematic approach when we encounter students who believe that relationships such as M1.V1=M2.V2 will be enough to solve the problem. It is very important that students identify the solutions used in titration reactions. The student can establish a connection between the steps to be applied in titration calculations and knowledge and skill and solve the problems successfully in this way (Waddling, 1983). The most common errors encountered in solving volumetric analysis problems are errors made while writing the molecular formula for calculating the mole mass of the compounds or writing the mole rates incorrectly. Most students have difficulty in writing formulas and equating equations. Students who solve problems correctly mainly use formulas in their solutions, they often have difficulties in establishing a stoichiometric ratio through the formula. It is also stated that students focus on the algorithm and do not pay attention to the content of the concepts. The data obtained from the analysis performed in the titration experiment are either used to replace it in the formula or in a proportion. It should be clarified that the data is the concentration of acid (Anamuah-Mensah, 1981).

The rate of correctly calculating the result of the problem is N: 5 and the rate of incorrectly calculating it is N: 2. It was stated that 2 with effect value in $H_2SO_4$ would be moved to the opposite side of the equation as a division and less titrant would be spent for those with excess hydrogen in the explanations of those who made errors. The calculations section, which forms part of the volumetric analysis, intimidates the students. Students find it difficult to develop the calculation part while they develop their practical techniques by experimenting (Johnstone, 1980). Students focus only on moving the variables in the relevant equations and directly reaching the result while solving chemistry problems. However, chemistry subjects should be related, and the cause-effect relationship should be comprehended. It should be ensured that chemistry teaching is enriched with experiments and thus, students should be questioned and comprehend the learning and cause-effect relationship (Aydogdu, 2000). Laboratory studies in chemistry should be an important component of course evaluation, otherwise, failure will occur. Creating a problem related to the subject in the laboratory, developing homework and questions are very important for students to become better problem-solvers (Wilson, 1987). If there are problems in understanding the problem, more problems arise in other steps. Students generally tend to memorize solutions according to the type of problem without dwelling on what is required in the question, without trying to understand the problem (Nakiboglu & Kalin, 2003). For a learning experience to be meaningful, students should be informed about their competencies, what level they are at, what they need to aim for and how to reach the determined standards (Andrade & Heritage, 2017). Here's what can be done to ensure that students understand problem-solving in chemistry: It should be ensured that students realize that the steps used to solve a problem are not the same for all problems. Understanding the problem followed in problem-solving, making plans for the solution of the problem, and evaluation steps should be supported by cooperative learning. Effective results are obtained in solving quantitative problems of chemistry lessons in this way (Bilgin, 2005). Techniques should be used to give students the opportunity to divide the problem solution into steps, to prevent turning to the wrong steps, to achieve the right result, and to obtain reliable results (Tatar, 2015). The use of applications such as flow chart in solving quantitative analysis problems. Solving the problems will be easier, the likelihood of students making mistakes will be reduced, the ability to reach the right result will be gained, and problem-solving will be made fun in this way (Karaer, 2020).

This study aims to determine the ways in which chemistry teacher candidates use volumetric analysis problems and to reveal the errors made. Problem-solving is very important in analytical chemistry. Applications should be made in theoretical courses and laboratories in order to improve the problem-solving performances of teacher candidates. Their problem-solving performances in other subjects of chemistry should also be examined. Teacher candidates should be given information about strategies and methods that they can use in their lessons and errors that students will make in problem-solving should be prevented according to the results.

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