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Problem-solving skills of high school students in chemistry

Maneerat Sa-ngiemjit[1], Ángel Vázquez-Alonso[2], María Antonia Manassero Mas[3]
[1]Faculty of Education, University of the Balearic Islands, Palma, Spain
[2]Center of Postgraduate Studies, University of the Balearic Islands, Palma, Spain
[3]Faculty of Social Psychology, University of the Balearic Islands, Palma, Spain

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ABSTRACT

People are continuously confronted with difficulties, which are situations that they do not understand yet strive to solve anyway. Researchers employed root cause analysis (RCA) in this study to analyze students' problem-solving in chemistry and the students' flaws and challenges in answering the subject. This research included 89 pupils from the secondary school's science-mathematics department. Students determined strategies to calculate pH and the color of the blended solution after each indicator was dropped. This study's qualitative method incorporates focus groups and content analysis. The majority of students properly identified the difficulty, and more than half correctly understood the problem. 100% of the pupils fared well in all processes since they were able to recognize and write all of the data. Using the RCA problem-solving technique, they were successful in identifying all of the data as potential causation aspects and the root causes of the problem. However, 37% of the pupils were unable to complete the problem. Investigating problem-solving flaws, it was determined that the students' defects in this problem-solving were application, analysis, practice, remembering, and time. Furthermore, researchers want to investigate the implementation of addressing the flaws in students' problem-solving to better prepare them for efficient problem-solving.

Corresponding Author:

Maneerat Sa-ngiemjit
Faculty of Education, University of the Balearic Islands
Palma, Balearic Islands, Spain
Email: m.sa-ngiemjit@uib.es

1. INTRODUCTION

People encounter challenges daily, and problem-solving can be found in every field of human inquiry and form of knowledge. However, only education will ensure pupils' success in the real world when they are confronted with problems. The definition of a real-world problem is a challenge where all of the facts, variables, requirements, questions, and relationships are aspects of reality [1]. To succeed in the world today, students must acquire skills for the twenty-first century, including problem-solving, innovation, creativity, metacognition, communication, and others. One of the most basic cognitive processes in humans is problem-solving. When students are presented with an instance where they are unsure of how to complete an assignment, a dilemma arises. Finding a workable solution or a way to the desired outcome involves systematic observation and critical analysis as part of the problem-solving process. Problem-solving is the process of learning information and the ability to assist the country's government by interfering with a set of procedures and objectives when the answer is unknown, unfamiliar, or reaches a new state of aim [2], [3].

In order to live a life of joy and wellness, problem-solving is crucial in all areas of life and is correlated to people's prior knowledge and experiences [4], [5]. The problem-solving framework is comprised of two fundamental skills: observation and critical thinking [6]. The observation skill is the capacity to collect data, absorb it, and interpret it using all of one's senses. Critical thinking comprises the ability to conceptualize, logically reason, apply strategy, engage in analytical thinking, decision-making, and synthesize any situation [6]. Students who can think clearly are able to solve problems successfully. Students need to be able to think critically and solve problems to be successful in school and in their personal and professional lives [7], [8]. Problem-solving is a form of cognitive ability that entails the process of determining solutions to difficult or intricate issues or obstacles [9], [10]. It refers to managing, assessing, and coming up with a solution [11].

The root cause analysis (RCA) approach seeks to determine why an unfavorable event occurred [12]–[14]. In science and engineering, RCA is a problem-solving technique that identifies the underlying causes of errors or problems [15]. The RCA procedure is divided into five steps: Step one is to characterize the problem by analyzing what you observe and identifying the specific symptoms to generate a problem statement. Step two is data collection; without comprehensive information and comprehension of the event, the causative variables and underlying causes linked to the event cannot be determined. Step three is to identify potential causative factors. Causal component diagramming provides a framework for investigators to organize and assess the information gathered during the investigation and highlight gaps and limits in understanding as the investigation progresses. Step four- to identify the root causes-a detailed examination of contributing elements leads to the discovery of the event's underlying process and system concerns (root causes). The circumstances that sparked the analysis should be expected to recur in the final step-recommendation generation and implementation-to generate recommendations for preventing its recurrence [12], [16], [17].

Chemistry issues can be tackled using a variety of methods. The factor-label approach is used by many chemistry lecturers and in most basic chemistry textbooks to demonstrate issue solutions. This strategy has been demonstrated to be ineffective for high school pupils with high mathematics anxiety and limited proportional reasoning abilities. The use of analogies and schematic representations leads to improved performance on tasks involving moles and molarity. One of the most difficult aspects of teaching beginner chemistry courses is assisting students in becoming effective problem solvers. This is one of the most challenging sections of the basic chemistry course for most students. Certain sorts of issues do not benefit from the use of analogs. Students are unable to answer even analog issues as difficulties get complicated (such as dilution problems) [18].

Chemistry in Thailand's secondary schools focuses on identifying and explaining that a substance is an acid or base using the acid-base theory of Arrhenius, Bernstead Lowry, and Lewis. Calculate and compare the dissociation or strength of acids and bases, and calculate the pH concentration of the solution's acid and base's hydronium ion or hydroxide ion. Write a chemical equation demonstrating the amino acid reaction and indicating the acid-base of the latter solution, the salt hydrolysis reaction, and the acidity base of the salt solution. Experiment with and explain the titration concept, select the appropriate indicator for acid-base titration; compute the substance or concentration of the acid or base solution from the titration, and discuss buffer solutions' characteristics, composition, and advantages. Finally, students can search for and offer examples of using and problem-solving with knowledge of acid-base [19].

In this study, we designed questions based on the curriculum so that students could calculate and compare the dissociation or strength of acids and bases, as well as determine the pH concentration of the hydronium ion or hydroxide ion of the acid and base solution. Write a chemical equation defining the titration concept, choose the appropriate indicator for acid-base titration, and determine the substance or concentration of the acid or base solution based on the titration. In addition, we insert the content of the electronic organization to prepare the student for entrance to the university. Moreover, we selected the RCA for solving this problem because we want to understand the students' faults and problems to solve the question and improve them for future problems. When teaching students to deal with practical problems, teachers should direct students to solve them in steps because it is difficult to work if they don't follow a specific sequence [20], [21].

2. RESEARCH METHOD

2.1. Research design

For this research, we used a qualitative technique, especially conducting in-depth case studies in the secondary school of Ramkhamhaeng University's Demonstration School (Grades 11, aged 17-18 years). The fieldwork was conducted from June to November 2022, and multiple techniques (content, organization, and process analysis) for gathering information were used with a group of students. The duration of the interview was 30 minutes, and the participants' data was anonymous and confidential. Content analysis and statistical data analysis were used to evaluate the data.

2.2. Study group

The study included 89 students from Bangkok's Ramkhamhaeng University's Demonstration School. During the first semester of the 2022 academic year, these pupils (41 males and 48 females) were enrolled in a scientific course. The students in grade 11 were divided into five classrooms.

In our focus group interviews, every participating student encountered challenges in generating and implementing ideas. Given the students' involvement in multiple classes, the teacher employed a simple random sampling method, selecting one student from each implementation as a representative (N=5). This approach aimed to ensure a diverse a representative sample reflecting the broader student population.

2.3. Data collection tool

Students in formal education are likely to confront difficulties in their chemistry studies. Unresolved means that an expert in the field acknowledges that an issue is unresolved, or that there is a lack of consensus among numerous experts on a solution to a given problem. In these circumstances, the condition is referred to as an unresolved problem in the field of study.

In this study, the first author collaborated with the chemistry instructor to create this question as shown in Figure 1 based on the school's curriculum. The student had 20 minutes to solve this question, and the teacher allowed pupils to use calculators on the proviso that the calculators could not send text messages to prevent students from communicating with one another. The researchers expected the students could identify the color of each indicator, which depended on the pH of the mixed solution. The pH of the mixed solution was 2.98, and each indicator had the following pH values: pHInA=1.20-3.20, pHInB=2.30-4.30, pHInC=3.20-5.20, and pHInD=1.70-3.70. After the indicators were dropped in the solution combination, indicator A showed a green color, indicator B showed a red-purple color, indicator C showed a blue color, and indicator D showed a light green color.

A solution with a dissociation percentage of 100%, pH = 11.25, volume 45 cm^3 of metal with atomic number 55 as element, was titrated with the HF solution with a dissociation constant of 6.6×10^{-4} and pH = 5.87, volume 55 cm^3, the initial thymol blue indicator was found to be unchanged. After increasing the total base volume, the thymol blue indicator began to change color. The resulting solution was mixed when the thymol blue indicator began to change color. Divide into 4 bottles of the same volume. Then put indicators A, B, C and D in each bottle. The indicator has the following information.

Indicator type	K_{In} value	Color change
A	6.31×10^{-3}	Yellow → Blue
B	5.01×10^{-4}	Purple → Red
C	6.31×10^{-5}	Blue → Red
D	1.99×10^{-2}	Yellow → Green

I would like to know when each indicator is added to the mixed solution. What color does each indicator change to?

Figure 1. The question in chemistry

2.4. Data analysis

The RCA approach was used by a chemistry teacher and researchers to evaluate the students' answer papers. The review process included procedures such as defining the problem, collecting data, identifying likely contributing variables, and determining underlying causes, where the color of each indicator is determined by the pH of the mixed solution. The final stage involved developing and implementing solutions based on the findings.

The result of the discussion groups was a collection of audio recordings from the teacher, the raw material, which was filled with viewpoints. An instructor and one of the study's researchers then transcribed the recordings for assessment. This study used a conventional approach that was analyzed using content analysis techniques to interpret the information derived from the discussion coherently and respectfully. This study followed a standard authorized protocol, which created codes during data analysis. Table 1 depicts the two primary chemical problem-solving flaws that have been formalized for study. This study followed a standard authorized protocol, which created codes during data analysis.

Table 1. Analytical model

	Problem factors	Categories
What are the problems of the students in problem-solving	Personal	Remembering; Applying; Creation; Practice; Interpretation; Analysis
	External	Calculator; Timing; Writing equipment; Environment (temperature, noise...)

The data from the students' responses were conceptually and relationally examined using approaches to content analysis. First, the student's capacity to comprehend the question's intent and record the data it contained was taken into account. Second, the RCA process and query results are accurately summarized in Table 2. Third, describe in detail each phase of the RCA as it is depicted in Table 3. The solution phase of the students who could not figure out the right response to this issue was examined and displayed in Table 4.

Table 2. Two researchers evaluate the phase of implementing the specified approach

Application strategy	*f*	%
The correct approach, the right answer	56	63
The correct approach, the wrong answer	33	37
The erroneous approach, the right answer	0	0
The erroneous approach, the wrong answer	0	0

Table 3. The frequencies and percentages of RCA

Determined step of RCA		*f*	%
1.	Define the problem	89	100
2.	Data collection	89	100
3.	Identify possible causal factors	89	100
4.	Identify the root causes	89	100
5.	Recommends and implements solutions	56	63

Table 4. Evaluation of frequencies and percentages of the student's fault solution in each step

Step of solution		*f*	%
1.	Electron organization	0	0
2.	Find the concentration of each solution (Molar)	5	15
3.	Change Molar → Mole (each solution)	8	25
4.	Change Mole → Molar (mixed solution)	9	27
5.	Find the pH of the mixed solution	5	15
6.	Find the pH range of each indicator and specify the color of the mixed solution	6	18
	Total	33	100

3. RESULTS AND DISCUSSION

3.1. Analyses of problem solvers and problem-solving

In evaluating both a teacher's and a researcher's assessments of a particular issue, students adeptly described the problem, collected data, and identified probable causative elements with ease. The majority of pupils demonstrated a high level of accuracy in recognizing and understanding the fundamental reasons underlying the issue. Overall, students excelled in comprehensively addressing the problem under scrutiny.

It is clear that the task was understood by more than half of the students. Some pupils had trouble completing the challenge, particularly in the last stage. One of the most crucial components of finding a solution is comprehending the issue at hand. From this vantage point, it is presumable that students' difficulties in solving the problem are caused by their incomplete understanding of it.

3.2. Application strategy

According to Table 2, 63% of the students were successful in applying the chosen strategy for this problem. These pupils used the proper technique and discovered the correct solution. Even though 37% of the students picked the proper technique, they were unable to solve the issue correctly. It meant that every student had success using the right approach.

3.3. Determining step

Furthermore, none of the pupils chose any strategies to address the challenge. Students utilize the RCA approach to solve problems as in Table 3. For starters, they can properly describe the problem and specify the data collected (atomic mass, volume, pH, Ka, and KIn). They could also identify probable causal factors and the root causes of an issue. Probable causal factors, when weak acid reacts with a strong base, the students could have explained that there are three possibilities: i) if a weak acid was used up, a base solution was formed; ii) if a strong base was used up, an acidic buffer solution was formed; and iii) if both the weak acid and the strong base were used up, a base salt solution was formed. For the root causes, they could specify that all the possibilities of a mixed solution were known when comparing moles of acid and base; after that, they would know the pH of the mixed solution. In all processes, 100% of the students performed well since they were able to locate all of the material and write it completely. Finally, 63% of students could recommend and execute solutions, implying that 37% were unable to do so. It can be shown that students struggle with recommending and executing solutions because this phase requires a wide range of abilities. The researchers want to know how students with difficulty tackle the problem, so we designed the six processes to be easier to assess.

3.4. The evaluation of the solution

This finding shows that changing mole to molar (27% of the student's incorrect solutions) accounted for the majority of errors in mixed replies for this problem-solving. Similarly, they attribute 25% of the students' incorrect answers to changing the molar to the mole in each solution. Moreover, 18% of the student's incorrect solutions were the result of their failure to recognize the color of the mixture of solutions and the pH range of each indicator. Last but not least, the student miscalculated the concentration of each solution and the pH of the combined solution, which accounted for 15% of the student's incorrect solutions.

3.5. Interviews

The authors discovered that the pupils had difficulty with the proposed and implemented solutions; therefore, we want to know so that we can assist and enhance their abilities to solve future difficulties. After reviewing the answer, the researcher discovered that the pupils performed flawlessly in each stage. We wish to confirm the pupils' knowledge and errors, which were chosen by the teacher using simple random sampling. However, in this group, there was a representative for each implementation, and all students received their exams on the desk.

> Researcher: *What is the problem for you?*
> A (second step): *I think that I remember the formula, but I didn't know the application, I am confused with the formula of a strong and weak acid-base. Another problem was forgetting to change the pH of the base to the pOH for the calculated hydroxide ion.*
> B (third step): *For me, I didn't have the time for practice because I must help with the chores of my mother, so I couldn't do it… I could do the before step because I practiced your homework and truly understood it.*
> C (fourth step): *I agree with B because last week I was sick so I couldn't practice homework, which makes me fault this solution…Although I did not use all the volumes of the two solutions, I think that practice is important because it could help me do it fast.*
> D (fifth step): *For me, I think time is important because I spent a lot of time on the before step thinking about the formula because I forgot it. So, for the last step, I had little time to do it. Likewise, I could not split the time for this question …*
> E (sixth step): *I agree with A, I think that I couldn't apply the data because I knew the concept and remembered the formula for calculating the pH of the indicator, but I used KIn data in the table, which did not change to the pKIn for calculating the pH of the indicator…, which I think is a low analysis of this question.*

According to the participants' accounts, the flaw in problem-solving in chemistry arose when they did not practice their assignments or exercises. Furthermore, application and analysis had an impact on students' problem-solving flaws. Furthermore, some students' timing is off, but they all agree that this is due to thinking the formula, which suggests that the pupils could not remember the formula for calculating the pH of a strong and weak acid-base, and the pH of the indicator even though they had previously solved similar problems.

Although we interviewed the students at different stages of this study, their flaws could also be recognized. Students' flaws in this problem-solving situation were application, analysis, practice, remembering, and time management. On the one hand, students frequently discuss memorizing, comprehending, applying, and analyzing, all of which are essential to critical thinking. Correlating knowledge and the application of strategies used to solve problems using higher order thinking skills was difficult for students to do [22].

In the case of problem-solving, critical thinking was particularly important because critical thinking and problem-solving skills were connected, and these terms were frequently used interchangeably [2]. Moreover, the researchers found that remembering, understanding, applying, and analyzing, were dimensions of critical thinking, that played an important role in engagement in problem-solving. According to Paul and Elder [23], critical thinking requires self-direction, self-discipline, self-monitoring, and self-correction. They believed that critical thinking involves problem-solving abilities as a necessary part. In addition, Belecina and Ocampo [24] found that after applying problem situations, students' critical thinking in problem-solving increased dramatically. When pupils meet various issues, their critical thinking increases [25], [26]. Critical thinking, one of the 21st-century competencies, can be improved through problem-based learning [24], [27]. Additionally, problem-solving abilities are the most essential skill required by our society, a crucial component of improving students' grasp of subject matter, and a means of empowering them to meet life's problems in the future [28]. The researchers hope to teach students problem-solving techniques in the future through group projects because they are essential for success in both organizations and specific professions. Learning occurs as a result of community practice participation [29], [30].

4. CONCLUSION

According to the findings of our investigation, the majority of the students accurately grasped the problem, which is one of the critical aspects of finding a solution to the problem. It was discovered that the majority of the students were effective in implementing the suggested method for this challenge. Furthermore, when the researcher considered the determination step of the RCA, it could be shown that students struggle with recommending and implementing solutions because this phase requires a wide range of abilities. The researcher's evaluation of the student's fault solution found that the faults of students mostly changed from mole to molar in the mixed solutions for this problem-solving. In the same way, they fault changing the molar to the mole. In addition, the student made an error in finding the concentration of each solution and the pH of the mixed solution. To understand the fault of the student, the researcher interviewed the student at each step and found that the fault of students in chemistry problem-solving occurred when they did not practice their homework or exercises. Application, analysis, practice, remembering, and time were also the faults of students in this problem-solving process. The researchers would like to use the correlation between critical thinking and problem-solving to improve students' problem-solving. We anticipated that as students' critical thinking skills improved, so would their problem-solving abilities. The authors want to prepare students to solve problems efficiently in the future; they want to spend less time-solving problems and get quality results. Although this research demonstrates that the RCA examines students' problem-solving in chemistry and the students' shortcomings and obstacles in answering this subject, the growing demand for problem solvers requires developing students' problem-solving skills. If the pupils can identify their weaknesses and improve their problem-solving skills, they will be regarded as excellent individuals.

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BIOGRAPHIES OF AUTHORS

Maneerat Sa-ngiemjit is a Ph.D. candidate, Faculty of Education, University of the Balearic Islands, Palma, Balearic Islands, Spain. She focuses on identifying learning styles and developing the students' learning skills because learning is a lifelong process and a continuous and never-ending action. She can be contacted at email: m.sa-ngiemjit@uib.es.

Ángel Vázquez-Alonso is a professor, Center of Postgraduate Studies, University of the Balearic Islands, Palma, Balearic Islands, Spain, and he is a researcher interested in improving school success by acting on critical variables in the context of science teaching and general teaching (basic skills and transversal skills, critical thinking, and scientific thinking) and the education of scientific, technological, and critical thinking skills through the teaching of topics of a science and technology nature. As well, he is involved in teacher training: the development and assessment of didactic content knowledge for teaching and learning scientific content. He has extensive experience in research, classroom application, and advice within the line of research that stems from different national and international projects and publications. He can be contacted at angel.vazquez@uib.es.

Maria Antonia Manassero Mas is a professor, Faculty of Social Psychology, University of the Balearic Islands, Palma, Balearic Islands, Spain. She is the principal investigator and member of the research teams in competitive projects financed by regional, national, and international institutions and organizations on topics related to her lines of research: stress, burnout, emotional work in the service sector, attitudes toward science, technology, and society, as well as gender, health, and quality of life. She currently teaches undergraduate studies in psychology and labor relations, as well as in the UIB's own title, International Hotel Management. She is an evaluator for different regional, national, and international agencies, as well as for national and international magazines. Member of the Academic Committee of the Doctorate in Education. She can be contacted at ma.manassero@uib.es.