Vol.12(2),2023, 273-282 DOI: 10.23960/jppk.v12.i2.2023.27
Jurnal Pendidikan dan Pembelajaran Kimia
e-ISSN: 2714-9595| p-ISSN 2302-1772
http://jurnal.fkip.unila.ac.id/index.php/JPK/index

Structure of Problem Solving in Critical Thinking Problems of Inorganic Compounds and Their Reactions

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Received: July 20th, 2023 Accepted: July 25th, 2023 Online Published: August 2nd, 2023

Abstract: Structure of Problem Solving in Critical Thinking Problems of Inorganic Compounds and Their Reactions. Solving problems in chemistry sometimes cannot be separated from one another. There are lots of subject matters that are interrelated with each other, which will affect the understanding of advanced material if the basic material is not understood. Objectives: This study aims to analyze the level of critical thinking skills and examine the structure of students' thinking when solving critical thinking questions on inorganic compounds and their reactions. Methods: This study uses a descriptive research method with a quantitative approach. This study involved 30 students who participated in general chemistry courses. The research data was obtained from the results of the analysis of critical thinking test answers on inorganic compounds and their reactions. The list of multiple-choice questions using a critical thinking level and an interview section were formulated to identify difficulties in understanding the material. Findings: From the data obtained, a summary of the category level of critical thinking 3% are deficient, 67% are moderate, 23% are good, and 7% are excellent. Based on the interview, the difficulties faced by students related to their ability to connect their understanding between the sub-micro level (particle models) and the symbolic level (chemical notation) and predict the results of the reaction, and the difficulty connecting with previous material, and Conclusion : The majority of students' critical thinking skills are still low. The ideal learner should rank from the macroscopic level and the technical terms used to describe chemical phenomena (symbolic) before they begin to discuss the explanation of the next micro (molecular) domain.
Keywords: Problem solving, critical thinking, inorganic compounds and their reactions

Abstrak: Struktur Penyelesaian Masalah dalam Soal-Soal Berpikir Kritis Senyawa Anorganik dan Reaksi-reaksinya. *Menyelesaikan permasalahan-permasalahan dalam materi kimia kadangkali tidak bisa dilepas antara satu dengan yang lainnya. Banyak sekali materi pokok yang saling berkaitan satu dengan lainnya yang akan mempengaruhi pemahaman materi lanjutan bila materi dasarnya tidak dipahami. Tujuan: Penelitian ini bertujuan untuk menganalisis tingkat kemampuan berpikir kritis dan memeriksa struktur berpikir peserta didik pada pemecahan masalah soal berpikir kritis pada senyawa Anorganik dan reaksi-reaksinya. Metode: Penelitian ini menggunakan metode penelitian deskriptif dengan pendekatan kuantitatif. Studi ini melibatkan 30 mahasiswa yang berpartisipasi pada mata kuliah kimia umum. Data penelitian diperoleh dari hasil analisis jawaban tes berpikir kritis pada materi senyawa anorganik dan reaksi-reaksinya. Daftar pertanyaan pilihan ganda menggunakan level berpikir kritis dan bagian wawancara dirumuskan untuk mengidentifikasi kesulitan-kesulitan dalam memahami materi., Temuan: Dari data diperoleh rangkuman tentang kategori level berpikir kritis 3% defiecient, 67% moderate, 23% good, 7% excellent. Berdasarkan wawancara kesulitan yang dihadapi mahasiswa terkait kemampuan untuk menghubungkan pemahaman menghubungkan tingkat sub mikro (model-model partikel) dan tingkat simbolik (notasi kimia), memprediksi hasil reaksi, dan kesulitan menghubungkan dengan materi sebelumnya., dan Kesimpulan: Mayoritas kemampuan berpikir kritis peserta didik masih rendah. Pembelajaran yang ideal seharusnya mengurutkan dari level makroskopik* *dan istilah-istilah teknis yang digunakan untuk menggambarkan fenomena kimia (simbolik) sebelum mereka mulai membahas penjelasannya selanjutnya domain mikro (molekul).*

Kata kunci: *Problem solving, berpikir kritis, senyawa anorganik dan reaksi-reaksinya.*

• INTRODUCTION

The ability to think critically is one of the goals of science education in the age of information technology (Kemendikbud, 2016; *Preus*, *2012*). The very rapid development of science and technology underlies the need for graduates who have the ability to reason and think critically (Alkharusi et al., 2019; Durant & Sendag, 2012). Critical thinking is the skill of thinking rationally (reasonably) by carrying out reflective activities to examine beliefs and decisions (Ennis, 2016).

Critical thinking is a skill that is taught to students and requires habituation (Fadiawati et al., 2022; Suarniati. et al.,2018). Critical thinking skills will produce a systematic and organized thinking process. A systematic thinking process is needed to formulate and evaluate the findings obtained based on evidence, assumptions, and logic that can be accounted for (Mahmudah & Yonata, 2020; Sari et al., 2019, 2021).

In the process of practicing critical thinking skills in the learning process, students will be directed to think and reason logically in order to be able to connect ideas, conduct research, evaluate arguments, and find inconsistencies and errors in their own work and the work of others. Solve complex problems and engage in reflection (Greenstein, 2012; Sari et al., 2021; Thaiposri & Wannapiroon, 2015). The application of critical thinking to students who take chemistry as a career will be faced with the process of solving problems in the field of work, for example, the synthesis of certain organic compounds from plants or from other natural materials (Suarniati et al.,2018).

Experts have different views on how to teach critical thinking skills to students. There are experts who argue that this ability must be carried out outside the context of the curriculum or not related to the subject matter. But (Gelder, 2005) argues differently; he states that critical thinking exercises can be carried out in a variety of contexts. Ennis and Facione mediate differences of opinion by stating that critical thinking can be done regarding certain topics and can also be applied to certain subject matter, with material content taken from everyday events (Sani, 2021).

It is important to know the process of critical thinking when practicing critical thinking skills in learning. The methods used to train critical thinking skills during the learning process are by presenting divergent questions so that students are accustomed to using logic and reasoning. Questions like "why, how, and explain" should be asked more than convergent questions (what, who, when, and where), which are only designed for short and simple answers and involve fewer mental (reasoning) processes (Eliasson et al., 2017).

In this study, the structure of students' critical thinking was examined for solving questions about inorganic compounds and their reactions. This material is the basic material for understanding further chemical concepts such as stoichiometry, advanced inorganic chemistry, etc.

Inorganic compounds are another category of chemical compounds other than organic compounds. Inorganic compounds are the antithesis of organic compounds. Understanding the constituents of organic compounds will help you understand how inorganic compounds are characterized. A substance that lacks carbon-hydrogen bonds, often known as C-H bonds, is referred to as an inorganic substance. In addition, inorganic substances are also characterized as building blocks of minerals or non-living matter (Brown et al., 2012; Speight, 2017).

In addition, inorganic substances frequently have a geological or mineral origin and lack carbon-to-hydrogen bonds. Most inorganic compounds—not all—contain a metal. In actuality, inorganic compounds make up the majority of all compounds in the universe. Because of this, inorganic compounds have a vast array of applications and practical usage in the real world.

The human body is not only composed of organic compounds but also inorganic compounds such as water and minerals. Minerals that exist in the body include calcium phosphate $Ca_3(PO_4)_2$, calcium carbonate ($CaCO_3$), magnesium phosphate $Mg_3(PO_4)_2$, CaF, calcium fluoride making up teeth, NaCl in human body fluids, and HCl in the stomach (Rey et al., 2009).

Some simple carbon compounds that lack C-H bonds are often considered inorganic. Examples include the allotropes of carbon (graphite, diamond, and buckminsterfullerene, etc.), carbon monoxide

(CO), carbon dioxide (CO_2), carbides (CaC_2), and the following salts of inorganic anions: carbonates (CO_3^{2-}), cyanides (CN^-), cyanates (OCN^-), and thiocyanates (SCN^-).

Inorganic compounds and their reactions are basic materials for understanding advanced materials such as stoichiometry and advanced inorganic chemistry. The majority of topics in chemistry lessons are sequential and structured (Sibanda & Hobden, 2016). Chemical concepts cannot be separated from each other (Nurhafizah et al., 2018), so students' inability to understand chemical concepts covered in the previous material will hinder their ability to understand chemical concepts covered in the next material.

Inorganic chemistry is also a very broad and complicated branch of chemistry. Inorganic chemistry has a wide variety of compounds and a large number of compounds because their compounds involve approximately 118 elements as gases, liquids, or solids, whose reactions are also quite complex. Inorganic compounds can be formed from ionic, covalent, and metallic bonds. Therefore, students must have a strong basis for understanding what inorganic compounds are and how they react (Ebbing, & Gammon, 2017).

Inorganic chemistry deals with the properties and behavior of inorganic compounds, which include metals, minerals, and organometallic compounds. Basic guidelines for naming the three subcategories of inorganic substances: ionic compounds, molecular compounds, acids, and salts, will be discussed in this section. Or it could be based on groups of oxides, acids, bases, and salts (Nelson, 2011).

The elements that form inorganic compounds consist of: 1) non-metal elements, such as carbon dioxide (CO_2), sulfuric acid (H_2SO_4), and diphosphorus pentoxide (P_2O_5); 2) metal and non-metal elements, such as tin tetrachloride ($SnCl_4$) and aluminum trichloride ($AlCl_3$). Inorganic compounds are bound to each other by ionic, covalent, and metallic bonds (Houk & Proust, 1996; Saito et al., 1996; Speight, 2017).

Through this material, critical thinking skills can be trained using questions that meet the criteria for critical thinking. One of the test formats that can be used to train critical thinking skills is open-ended testing in the form of multiple-choice tests with written reasons (Ennis, 2011). The purpose of this research is to examine the level of critical thinking skills and the structure of students' thinking when solving critical thinking questions on inorganic compounds and their reactions.

• METHOD

This study uses a descriptive research method with a quantitative approach (Sugiyono, 2017). This study will describe students' thinking skills in solving critical thinking questions on inorganic compound materials and their reactions. The participants involved in this research were semester 1 students who took general chemistry courses at Medan State University.

The research data was obtained from the analysis of critical thinking test answers on inorganic compounds and their reactions and from data from interviews to diagnose students' difficulties in solving critical thinking questions on inorganic compounds and their reactions. The instruments used were critical thinking tests and interviews. Critical thinking questions use multiple choice and reasons. The assessment instructions are explained in Table 1.

Table 1. Assessment Guide

	Score
The choice is correct.	1
The reasons given are true and correct.	2
The reason is less than perfect.	1
The choices and reasons given are wrong.	0

The maximum total score is obtained if the multiple-choice answers are correct and the reasons given are correct according to the rubric. Then you will get a maximum value of 3. If the choice is correct but the reason is not perfect, the score is 2. If the choice and reason given are incorrect, the score is 0.

According to (Facione, 2015), the critical thinking test is composed of five critical thinking indicators, namely: interpretation, analysis, evaluation, inference, and explanation.

Table 2. Critical Thinking Indicators, according to Facione

Indicator	Sub-Indicators
1. Interpretation	a. Create blueprints b. Categorization c. Clarifying d. Paraphrase someone's idea using your own words
2. Analysis	a. Ability to check ideas b. Detect arguments c. Analyze arguments d. Identify similarities and differences between the two approaches to the solution of a given problem
3. Evaluation	a. Assess the credibility of the statement b. Describes a person's perception, which is meant by the relationship between statements
4. Inference	a. Identify and obtain the elements necessary to draw a reasonable conclusion b. Form alternative conjectures and hypotheses

The questions were reviewed by a chemical content expert and a general chemistry teacher. The interview instrument aims to diagnose the difficulties you experience when answering critical thinking questions.

The data analysis technique uses descriptive analysis, which is displayed in the form of frequency distribution tables, histogram tables, mean values, standard deviation values, and others. In the descriptive analysis, the average value, maximum value, minimum value, mean value, standard deviation, mode value, and others are obtained. Student critical thinking data is categorized based on qualitative categories adapted from Johnson & Christensen (2019).

Table 3. Percentage of The Critical Thinking Category

Persentage	Category
$X \geq 80\%$	Excellent
$60\% \leq X < 80\%$	Good
$40\% \leq X < 60\%$	Moderate
$20\% \leq X < 40\%$	Defiecient
$X < 20\%$	Poor

• RESULT AND DISCUSSION

The data obtained from this study came from answers to critical thinking questions and interviews with 30 students involved in the research. In this study, critical thinking processes were identified by using questions on inorganic compounds and their reactions. The questions are designed using critical thinking indicators, according to Facione (2015). The following is a description of student achievements for each question.

Table 4. Percentage of Student Answers to Each Question

Critical Thinking Indicator	Description of the question	% Number of students	Category
1. Interpretation: create *blue print*	**Question Number 1 :** Students interpret the description of chemical reactions in symbolic form.	42%	Moderate
	Question Number 10 : Interpret the single exchange reaction shown in the figure.	27%	Deficient
2. Analysis : (ability to examine ideas, detect arguments, and identify similarities and differences).	**Question Number 2 :** Combine existing cations and anions so that they match the results in the picture.	18%	Poor
	Question Number 4 : Choose the correct reaction of an acidic oxide compound with water to form its acidic compound.	47%	Moderate
	Question Number 5 **:** Choose the correct reaction of a basic oxide with water to form a basic compound.	52%	Moderate
	Question Number 7 : Analyzing the right compounds to use for acidic soils	71%	Good
3. Inference : (to identify and obtain the elements necessary to describe kesimpulan yang masuk akal).	**Question Number 3 :** Summarize the category of reactions based on their characteristics.	82%	Excellent
	Question Number 6 : Based on the guide table regarding the solubility of compounds in water, conclude the compounds formed from these reactions and determine the reactions that precipitate.	49%	Moderate
	Question Number 9 : Formulate conjectures or hypotheses.	44%	Excellent Moderate
4. Explanation : (explaining methods and results, justifying procedures, proposing and justifying something with reasons)).	**Question Number 8** : Apply the procedure for balancing redox reactions.	61%	Good

From these ten questions, question number 7, all participants answered correctly, but only four gave correct and appropriate reasons. The problem is as follows:

7) A farmer is confused because his land is less productive than before after being affected by acid rain from a volcanic eruption. Even though he has routinely added nitrogen and ammonia fertilizers with the intention of fertilizing his land. After checking the soil pH, a pH of 2 was obtained. According to the expert's view, excessive use of nitrogen fertilizers actually causes the soil pH to become acidic because bacteria in the soil oxidize NH_4^+ ions to nitrates, NO_3^-. From the following substances :

(1) K_2HPO_4 (2) NH_4NO_3 (3) $CaCO_3$ (kapur) (4) $CO(NH_2)_2$

From the four compounds, choose one that can be added by farmers so that their land is productive again …

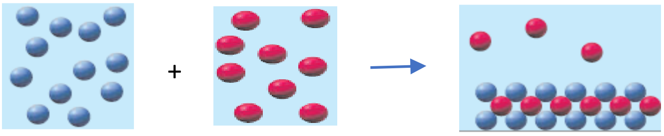
a. (1) dan (2) b. (1) dan (3) c. (2) dan (3) d. (2) dan (4) e. (3) dan (4)

Reason : ………………………………………………………………………..

Some students are quite perfect at answering questions by connecting them with hydrolysis material, such as the following answers:

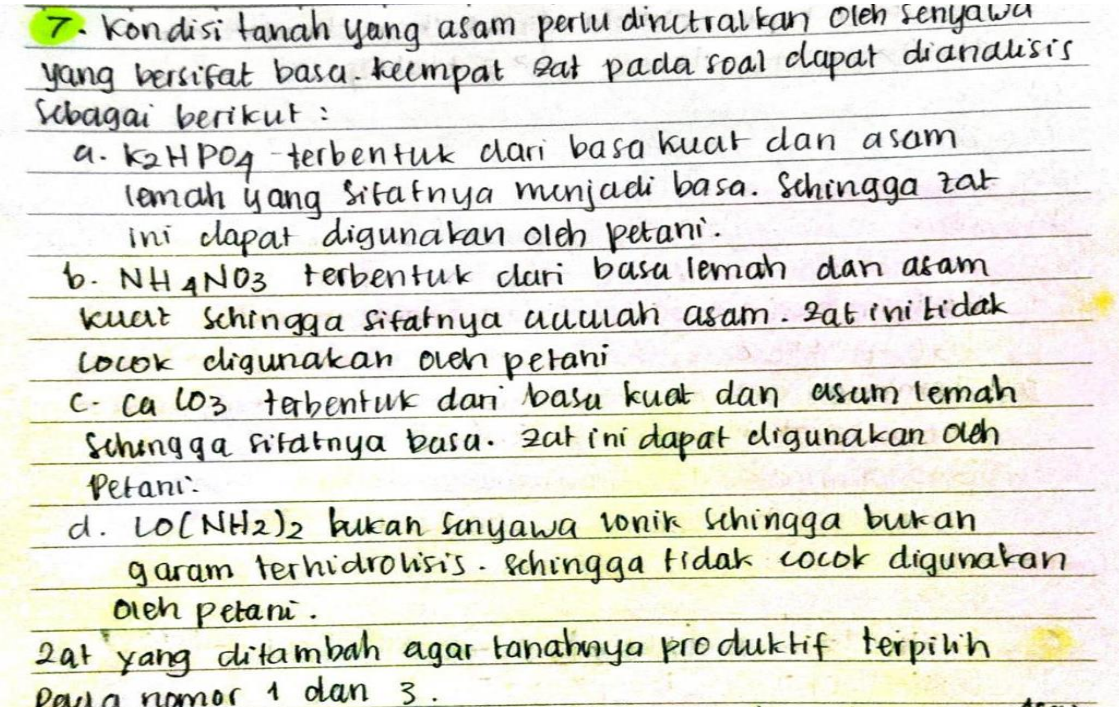
(2) Assume that an aqueous solution of cations, represented as blue balls, is mixed with a solution of anions, represented as red balls. Here are some cations and anions. Combine the existing cations so that they match the results in the picture:

Cations : Na^{+}, Ca^{2+}, Ag^{+}, Ni^{2+}
Anions : Cl^{-}, CO_3^{2-}, CrO_4^{2-}, NO_3^{-}



(a) $AgCl$; $Ni(NO_3)_2$; Na_2CO_3 ; $Na_2CrO_4^{2-}$
(b) Ag_2CrO_4 ; Ag_2CO_3 ; Na_2CO_3 ; Na_2CrO_4
(c) Ag_2CrO_4; Ag_2CO_3 ; $Ni(NO_3)_2$; $NaNO_3$
(d) $CaCrO_4$; Ag_2CO_3 ; $Ni(NO_3)_2$; $NaNO_3$
(e) $CaCrO_4$; $AgNO_3$; $Ni(NO_3)_2$; $NaNO_3$

Reason : …………………………………………………………


7. Kondisi tanah yang asam perlu dinetralkan oleh senyawa yang bersifat basa. keempat zat pada soal dapat dianalisis sebagai berikut :
a. K_2HPO_4 terbentuk dari basa kuat dan asam lemah yang sifatnya menjadi basa. Sehingga zat ini dapat digunakan oleh petani.
b. NH_4NO_3 terbentuk dari basa lemah dan asam kuat sehingga sifatnya adalah asam. zat ini tidak cocok digunakan oleh petani
c. $CaCO_3$ terbentuk dari basa kuat dan asam lemah sehingga sifatnya basa. zat ini dapat digunakan oleh petani.
d. $CO(NH_2)_2$ bukan senyawa ionik sehingga bukan garam terhidrolisis. sehingga tidak cocok digunakan oleh petani.
zat yang ditambah agar tanahnya produktif terpilih pada nomor 1 dan 3.

In question no. 2, only one person can answer correctly, but the reason is incorrect. The expected answer is that the student refers to the ratio of the blue (cation) and red (anion) balls that are bonded, namely: 2: 1. So the bonded cation is charged one, and the anion is charged two. In question no. 2, it is quite complex because you have to be able to interpret the meaning of the image and combine it with the available cations and anions. This is what makes it difficult for students to answer the question correctly and explain the reasons.

The summary of the data obtained about the overall critical thinking level category owned by the 30 students who participated in the measurement of the critical thinking level is illustrated in the following figure 1 graph:

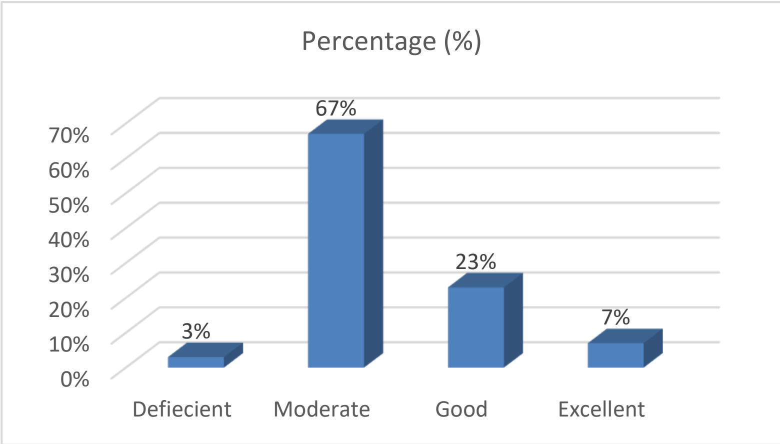


Figure 1. The Level of Students' Critical Thinking

After conducting a test to check students' thinking skills on inorganic compounds and their reactions, interviews were conducted to find out students' difficulties in answering critical thinking test questions. Some students answered that they had never practiced with the questions being trained. Students have difficulty expressing the reasons for the answers they give. For example, in number 7, all students answered correctly, but the reasons given were for only four students who answered correctly.

In questions numbers 2 and 3, the questions given were about conducting a test to check students' thinking skills on inorganic compounds and their reactions. Interviews were conducted to find out students' difficulties in answering critical thinking test questions. Some students answered that they had never practiced with the questions being trained. Students have difficulty expressing the reasons for the answers they give. For example, in number 7, all students answered correctly, but the reasons given were for only four students who answered correctly.

In chemistry classes, critical thinking skills are indispensable for advancing a solid understanding of basic chemistry concepts. The ability to relate understanding connects the sub-micro level (particle models) and the symbolic level (chemical notation). Students have difficulty connecting these two levels. Critical thinking skills are needed to connect levels in chemistry learning (Bain et al., 2014; Hernández et al., 2014).

The ideal learning sequence is so that students can understand step by step, starting from the macroscopic level and the technical terms used to describe chemical phenomena (symbolic), before they start discussing the explanation, which requires an understanding of the micro (molecular) domain. Johnstone argues that if the three levels are given simultaneously, it will result in an overloaded working memory. So that students cannot accommodate these overlapping chemical concepts (Johnstone, 2006).

They also pointed out difficulties in predicting the outcome of reactions, for example, single-exchange reactions, double-exchange reactions, and reactions of oxide compounds with water. Students also still have difficulty determining the compounds formed from cations and anions represented by pictures.

The majority of students understand the material of inorganic compounds, and their reactions still rely on memorization. For example, memorizing so many chemical compounds will be very risky because chemistry lessons are a frightening specter because you have to memorize so many compounds. For example, students must memorize the formulas for ammonium sulfate $(NH_4)_2SO_4$; sodium perchlorate ($NaClO_4$); calcium nitrate ($Ca(NO_3)_2$); potassium chromate (K_2CrO_4); and potassium dichromate (K_2CrO_7). You don't need to memorize these compounds; what you need to memorize are polyatomic anions. For monoatomic cations, you don't need to memorize anything; you just need to know the charges that the cation has.

To understand this material, start with the periodic system of elements, chemical bonds, which study the types of bonds, and the nomenclature rules of ionic compounds and molecules. It is better for students to be introduced directly to these compounds while remembering their shapes and colors. Students who are still learning at the concrete level will find it easier to remember and understand this information.

Each student has prior knowledge, such as initial knowledge, which becomes an element of building new knowledge. It's just that the level of complexity of prior knowledge is also a factor in the success of building new knowledge, and this is a challenge for students in learning (Maulidya & Saputri, 2016).

In some textbooks, the material for inorganic compounds and their reactions is given after the material for the periodic system of elements, molecular compounds, ionic compounds, and chemical bonds. The previous materials provided information about the charges of the main group and transition group elements. In the discussion chapter on main groups, information is provided about how elements form positive and negative charges as well as transition groups. In this chapter, students are expected to recognize: 1) monoatomic and polyatomic cations; 2) Monoatomic anions and polyatomic anions.

Based on an understanding of the periodic system of elements in terms of main groups and transition groups, students can understand chemical bonds that predict the compounds formed from bonds between these cations and anions. If students do not understand this material, they will be confused about the placement of ionic charges as subscripts in the formation of ionic compounds. This continues the difficulty of predicting the reaction results of these inorganic compounds, which consist of: 1) Decomposition reactions; 2) Combination reactions; 3) Displacement reactions; and 4) Exchange reactions (Metathesis).

This is what becomes difficult for students, such as reorganizing knowledge to connect prior knowledge with new knowledge. They understand chemical material separately from previous material. They have difficulty connecting new material with previous material. This is in line with previous research regarding difficulties regarding the correct use of subscripts and coefficients. Additionally, there is confusion about the presence of polyatomic ions in the reacting compounds. The idea that they have in mind is that polyatomic ions will dissociate into smaller particles in water (Naah & Sanger, 2012).

• CONCLUSION

In chemistry classes, critical thinking skills are indispensable for advancing a solid understanding of basic chemistry concepts. From the research data, a summary of the critical thinking level categories was obtained: 3% deficient, 67% moderate, 23% good, and 7% excellent. The majority of students' critical thinking skills are still low. The summary obtained from interviews about students' difficulties in completing critical thinking tests is due to their limited prior knowledge, so they are unable to organize the knowledge received and relate it to previous knowledge. This can be seen from the confusion of placing the ion charge as a subscript in the formation of ionic compounds and the difficulty in understanding the relationship between the sub-micro level (particle models) and the symbolic level (chemical notation).

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