



Analysis of Misconceptions on Material Solubility and Solubility Product (Ksp) Using a Four Tier Diagnostic Test Instrument

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Abstract:

Solubility and solubility product (Ksp) have the potential to be chemical materials that can cause misconceptions in students. The characteristics of material that are abstract, concrete and contain mathematical calculations are often the reason this material is considered difficult to understand. This research aims to analyze the misconceptions experienced by students regarding solubility and Ksp material. This research uses a descriptive method with a quantitative approach. The population of this study were all students of class XI Science at SMAN 1 Pronojiwo and all of them were the sample in this study. The sampling technique used is a saturated sample. The data collection instrument developed and used in this research is a four tier diagnostic test instrument. The data analysis technique uses quantitative descriptive which is guided by the results of the percentage of misconceptions experienced by students in each sub-concept of solubility and Ksp material as well as each question item. Based on the research results, it was identified that in general students' misconceptions regarding solubility and Ksp material were in the low category with a percentage of 23.35%. The highest percentage of misconceptions was identified in the sub-concept of the influence of pH on solubility at 26.62%. Meanwhile, the lowest percentage of misconceptions was identified in the sub-concept of determining the solubility(s) of salts or hydroxides that are difficult to dissolve at 17.48%.

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Introduction

The stigma that chemistry material is relatively difficult to learn and understand still lingers in students' minds. This may be due to the characteristics of chemical materials, which are primarily abstract and accurate and require reasonable calculation and analysis skills. Apart from that, it is suspected that the learning model applied in class has yet to accommodate students' learning styles and the need to deliver chemical material based on their characteristics. Data on student learning outcomes are relatively low on this material in several schools' research results; [Sudiana et al., \(2019\)](#); [Muderawan et al., \(2019\)](#); [Ihsan et al., \(2021\)](#) also contributes to the fact in the field that this stigma is indeed true. The fact that learning outcomes are relatively low indicates that students are experiencing learning difficulties, but it is not yet clear what type of difficulties they are. To identify students' learning difficulties, it is necessary to carry out diagnostic efforts that lead to efforts to analyze learning difficulties and the factors that cause them. This is important because information about students' weaknesses will be obtained by carrying out a diagnosis, and they can identify learning problems ([Inggit et al., 2021](#)).

Solubility and solubility product (K_{sp}) are chemical materials that, in several studies, have stated that students have difficulty learning them. According to [Hidayah et al \(2013\)](#) students' learning difficulties in this material are caused by needing to understand the prerequisite material and making mistakes in connecting concepts. This material includes the concept of moles, ionization reactions, chemical equilibrium, and the pH of acid and base solutions. Several other research results from [Magfirah \(2011\)](#); [Ulfa et al., \(2016\)](#); [Sudiana et al.,\(2019\)](#); [Rosyada F et al., \(2021\)](#) also show that, in general, students experience difficulties in studying and understanding solubility and K_{sp} material from different aspects and concepts. Difficulties in understanding this concept have the potential to cause misconceptions. If students correctly understand the concept, they can continue and understand the next concept. Then, the initial concept that has been understood is needed to understand the next concept. On the other hand, if there is an error in understanding a concept, it can affect the understanding of other concepts.

Misconceptions are a wrong understanding of certain concepts, so they are not in accordance with scientific concepts or those understood by experts in a particular field ([Suparno, 2013](#)). According to [Mondal & Cakhraborty \(2013\)](#) things that can cause misconceptions include daily experiences, how teachers teach, and textbooks. If not handled properly, misconceptions can become learning problems in the classroom ([Priyasmika & Sholichah, 2022](#)), can hinder students' understanding in accepting new concept ([Gurel et al., 2015](#)), and can even cause students to experience more complex conceptual errors ([A'yun & Nuswowati, 2018](#)). So, it is necessary to identify misconceptions early in the learning proces ([Raharjo et al., 2019](#)). Based on this review, it is considered essential to carry out efforts to identify misconceptions as a first step in minimizing the occurrence of student misconceptions. One instrument that can identify misconceptions is the four-tier diagnostic test.

The four-tier diagnostic test instrument is one type of multi-tier test instrument. This instrument can be used to identify student misconceptions in science education ([Gurel et al., 2015](#)) and to measure the level of misconceptions ([Abbas, 2019](#)).

According to ([Roghdah et al., 2021](#)) this four-tier diagnostic test instrument is in the valid category and is by learning. This instrument, a development of the three-tier diagnostic test, consists of four levels of questions. The first level is in the form of questions related to the concept being studied, the second level is related to statements of the level of confidence in the answer choices at the first level, the third level is in the form of reasons for the answers to the first level questions, and the fourth level is a statement of confidence in the answer choices at the third level.

Ultimately, this research aims to analyze students' misconceptions regarding solubility and K_{sp} material thoroughly. As in the previous explanation, it was stated that misconceptions can hinder the learning process in class and potentially cause the emergence of misconceptions sequentially in the following chemistry material if students need help understanding the concept in the previous material. This is important because early identification of misconceptions will help educators explain chemical concepts that need special handling or treatment in their learning. So that educators will consider and pay more attention to the use of teaching materials, learning methods, and evaluation tools. The next hope is to reduce student misconceptions and increase student understanding of chemistry material in general.

Research Method

The quantitative descriptive method chosen and used in this research aims to obtain information and data to describe with statistical figures related to students' misconceptions about solubility and K_{sp} . The population in this study were all students of class. These students had previously studied solubility and K_{sp} material, and the sampling technique used in this research was a saturated sample.

The data collection process was carried out using interview techniques and using a four-tier diagnostic test instrument. The interview stage was carried out with chemistry class teachers to gather various initial information regarding the learning and evaluation that had been carried out. Additionally, interviews were used to determine the teachers' responses to the test instruments. In the next stage, giving a diagnostic test aims to identify more deeply the level of students' understanding of 7 sub-concepts and questions about solubility and K_{sp} . The seven sub-concepts referred to are (1) determining the solubility(s) of salts or hydroxides that are difficult to dissolve; (2) writing the solubility product equation (K_{sp}); (3) the relationship between K_{sp} and solubility; (4) calculate the K_{sp} value and the solubility of salts or hydroxides that are difficult to dissolve; (5) the effect of the same ion on solubility; (6) the effect of pH on solubility; (7) estimates precipitate formation based on Q_c and K_{sp} values.

The test instrument given to students consisted of 15 questions which were the result of development by researchers with the distribution of sub-concept 1 in questions number 1 and 2, sub-concept 2 in questions number 3 and 4, sub-concept 3 in questions number 5 and 6, subconcept 4 in questions number 7 and 8, subconcept 5 in questions number 9 and 10, subconcept 6 in questions number 11 and 12, subconcept 7 in questions number 13, 14 and 15. Instrument validation in the form of expert validation was carried out, and a score of 96.43% was obtained. Instrument testing was carried out on different subjects from the sample, and an alpha value of 0.93 was

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obtained, which means this question has very high reliability according to the criteria in Table 1.

Table 1. Reliability Criteria

Reliability Score	Criteria
$0,81 < V \leq 1,00$	Very High
$0,61 < V \leq 0,80$	High
$0,41 < V \leq 0,60$	Medium
$0,21 < V \leq 0,40$	Low
$0,0 < V \leq 0,20$	Very Low

Data from students' answers to diagnostic test questions that have been obtained are then analyzed. Next, the results of the analysis of the answers are classified based on a combination of four-tier diagnostic test answers and understanding categories, as in Table 2 below.

Table 2. Combination of Four Tier Diagnostic Test Answers and Categories

Question Number	Answer Combination					Category
	Answer	Confidence Rating	Alasan	Confidence Rating	Category	
1	true	confidence	false	confidence		
2	true	inconfidence	false	confidence		Misconception
3	false	confidence	false	confidence		
4	false	inconfidence	false	confidence		
5	true	confidence	true	inconfidence		
6	true	confidence	false	inconfidence		
7	true	inconfidence	true	confidence		
8	true	inconfidence	true	inconfidence		Partially understand
9	true	inconfidence	false	inconfidence		
10	false	confidence	true	inconfidence		
11	false	confidence	false	inconfidence		
12	false	inconfidence	true	inconfidence		
13	false	inconfidence	false	inconfidence		
14	false	confidence	true	confidence		Misconception
15	false	inconfidence	true	confidence		
16	true	confidence	true	confidence		Understanding

(Gurel, 2015)

Data that has been analyzed based on a combination of answers and categories, according to Table 1, is then created as a percentage of the level of misconception. The percentage of misconceptions obtained was then categorized as being at a high, medium, or low level of misconception, according to Table 3 below.

Table 3. Level of Student Misconceptions

Percentage of Misconception (%)	Level of Misconceptions
0-30	Low
31-60	Medium
60-100	High

(Suwarna, 2013)

The percentage of student misconceptions is calculated using the formula:

$$P = f/N \times 100\%$$

Explanation:

P = Percentage (% Group)

f = Number of students in a particular category

N = Total number of students

The results of the percentage calculations are then analyzed to identify misconceptions experienced by students regarding solubility and Ksp material. Descriptive analysis was also carried out to identify misconceptions in each sub-concept and question item. The research procedure carried out briefly includes the following stages.

1) Initial Stage of Research

The first stage included a literature review, reviewing the concepts of solubility and Ksp material guided by the chemistry syllabus and K13 curriculum, and identifying misconceptions that often occur in this material.

2) Research Implementation Stage

At the implementation stage, interviews were carried out with chemistry teachers, and this was followed by data collection using a four-tier diagnostic test instrument for students who had previously studied solubility and Ksp material.

3) Research Data Analysis Stage

The data obtained was then analyzed to be categorized based on the type of understanding and level of student misconceptions. The results of data analysis are used to conclude.

Finding and Discussion

Research data obtained using the four-tier diagnostic test instrument was then analyzed and categorized based on a combination of students' answers into four categories of understanding consisting of understanding the concept (P), not understanding (T), partially understanding (S), and misconceptions (M). Data on students' conceptual understanding of solubility and Ksp material, which is divided into seven sub-concepts, is shown in Table 4 below.

Table 4. Categories of Student Understanding

Sub-concept	Question Number	Category (Percentage %)			
		P	T	S	M
1. Determine the solubility(s) of a poorly soluble salt or hydroxide	1, 2	80,04	1,24	1,235	17,48
2. Write down the solubility product equation (Ksp)	3, 4	76,25	1,87	0	21,87
3. Relationship between Ksp and solubility (s)	5, 6	63,125	6	6	24,87
4. Calculate the Ksp value and the solubility of salts or hydroxides that are difficult to dissolve	7, 8	64,05	6,79	5,15	24,03
5. Effect of the same ion on solubility	9, 10	69,25	5	2,5	23,25
6. Effect of pH on solubility	11, 12	67,12	1,25	5	26,62
7. Estimate the formation of deposits based on the Qc and Ksp values	13, 14, 15	70,17	2	2,5	25,33
Average Percentage		70	3,45	3,20	23,35

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The data in Table 4 shows that the average percentage of students in the categories of understanding the concept, not understanding, partially understanding, and having misconceptions is 70%, 3.45%, 3.2%, and 23.35%, respectively. These results also show that students' general misconceptions about solubility and K_{sp} are at a low level, namely 23.35%. The percentage of misconceptions that occur in the material, which contains seven sub-concepts, is depicted in a diagram in Figure 1 below.

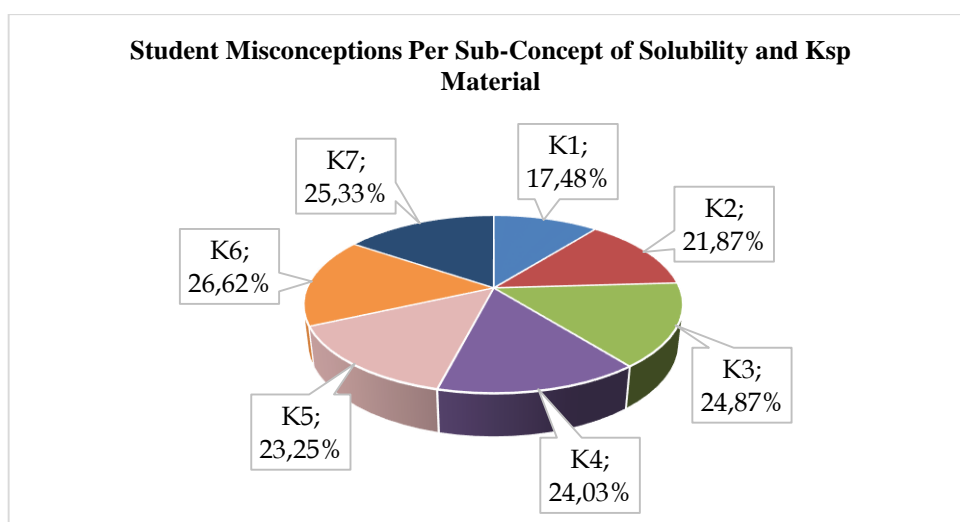


Figure 1. Student Misconceptions Diagram Per Sub-Concept

Explanation:

K1 = Sub-Concept 1

K2 = Sub-Concept 2

K3 = Sub-Concept 3

K4 = Sub-Concept 4

K5 = Sub-Concept 5

K6 = Sub-Concept 6

K7 = Sub-Concept 7

The data in the diagram shows that the percentage of misconceptions experienced by students varies in each sub-concept. In sub-concept 1, namely determining the solubility(s) of salts or hydroxides that are difficult to dissolve, the misconception that occurred was 17.48%. Next, in subconcept 2, namely writing the solubility product equation (K_{sp}), the misconception experienced by students was 21.87%. The misconception experienced by students in sub-concept 3 is the relationship between K_{sp} and solubility (s) of 24.87%. In sub-concept 4, namely calculating the K_{sp} value and the solubility of salts or hydroxides that are difficult to dissolve, students experienced 24.03% misconceptions. Next, for sub-concept 5, namely the influence of the same ion on solubility, the misconception experienced by students was 23.25%. In sub-concept 6, namely the effect of pH on solubility, the misconception experienced by students was identified at 26.62%. The misconception experienced by students in sub-concept seven is estimating the formation of precipitates based on Q_c and K_{sp} values of 25.33%.

The misconceptions experienced by students in each question item on solubility and K_{sp} material are shown in the graph in Figure 2 below.

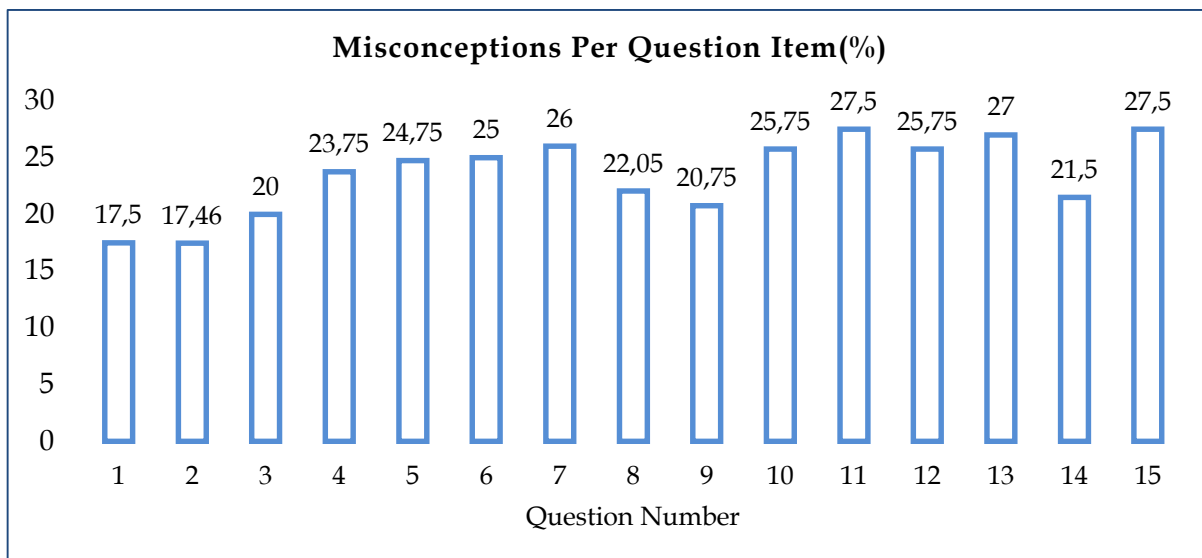


Figure 2. Student Misconceptions Per Question Item

Referring to the misconception category in Table 2 above, the percentage of misconception scores in Figure 2 shows that students' misconceptions per question item are in the low category because they are at $< 30\%$. In this category, the lowest misconception in question 1 in sub-concept one is determining the solubility(s) of salts or hydroxides that are difficult to dissolve, with a misconception percentage of 17.5% . Meanwhile, the highest misconceptions are in two different sub-concepts, namely in sub-concepts 6 and 7, to be precise, in questions number 11 and 15, with the same percentage of 27.5% . Question number 11 is related to the effect of pH on solubility, and question number 15 is about estimating precipitate formation based on Q_c and K_{sp} values.

The following is an explanation of students' misconceptions about seven sub-concepts of solubility and solubility product.

1. Determine the solubility(s) of a salt or hydroxide that is difficult to dissolve (question number 1 and 2)

Student misconceptions in question number 1 were identified at 17.5% . Students are asked to calculate the solubility of potassium chloride dissolved in water and determine the mass of filter paper and residue after filtering. This misconception can occur because students need clarification about determining the difference between salt, residue, and filter paper mass. Mistakes in understanding the concept of calculation caused misconceptions. This is closely related to students' low accuracy and ability to understand the basic concepts of mathematical calculation operations. Learning chemistry requires numeracy/mathematics skills as an essential ability so students can quickly solve problems ([Muderawan et al., 2019](#)).

In question number 2, 17.46% of students experienced misconceptions. Students are asked to determine the solubility of sodium chloride with various mass variations. Students assume that if three different masses of salt come from the same type of salt (NaCl), it will affect the solubility and produce different solubility. Whatever the mass variation of the same type of salt, it should have the same solubility value. Students'

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conceptual errors can come from incomplete understanding and the need to master initial concepts/prerequisites ([Arianto et al., 2016](#)).

2. Write the solubility product equation (K_{sp}) (questions number 3 and 4)

Data on the percentage of student misconceptions in question number 3 shows it to be 20%. Students are asked to write the K_{sp} equation and conclude the solubility of calcium hydroxide and barium hydroxide with the same mass if each is dissolved in 1 liter of water. The misconceptions experienced by students are due to students needing to understand the concept of the ratio between the mass of a substance and its effect on the solubility value. Students tend to assume that if two substances with different solubility values have the same mass, they will be equally soluble without considering whether their mass value is greater or less than their solubility value. Substances with a solubility value $<$ mass of the substance should dissolve, and substances with a solubility value $>$ mass of the substance will partially dissolve. In question number 4, 23.75% of student misconceptions were identified. Students are asked to write the equation for the reaction of mixing potassium chloride with phosphoric acid. Students must be more careful and make mistakes in balancing the number of reactant atoms in the equilibrium reaction. This is based on the results of research ([Ihsan et al., 2021](#)) which states that students need help writing the K_{sp} equation due to not being able to correctly write the equilibrium reaction equation for a saturated solution.

3. Relationship between K_{sp} and solubility (s) (questions number 5 and 6)

The percentage of student misconceptions in question number 5 is 24.75%. Students are asked to determine the K_{sp} expression for calcium phosphate. Students need to adequately understand the concept of the solubility product expression and be careful enough so that the formula used is inverted or incorrect in determining the reaction coefficient and its exponent. This is in line with the results of research ([Muderawan et al., 2019](#)) which states that the average student cannot write K_{sp} expressions correctly. Apart from that, the cause of misconceptions about this sub-concept is that students' mathematical abilities in the basic concepts of roots and exponents still need to improve. ([Ulfa et al., 2016](#)).

Meanwhile, misconceptions in question number 6 are known to be 25%. Students are asked to calculate the K_{sp} value of sodium sulfate. Students are confused in determining the K_{sp} calculation formula and make mistakes in determining each ion's coefficient values and powers involved in the reaction. Apart from that, students still struggle to determine ionic equilibrium reactions and calculate multiplication and roots of decimal numbers. This is supported by research results ([Ihsan et al., 2021](#)) which state that students have difficulty linking the concepts of solubility and pH and have not mastered mathematical calculation operations well in this sub-concept.

4. Calculate the K_{sp} value and the solubility of salts or hydroxides that are difficult to dissolve (numbers 7 and 8)

In question number 7, student misconception data was obtained at 26%. Students are asked to summarize the 2-dimensional image of the ions resulting from

the dissolution of silver chloride with three different mass variations into water. Students assume that the smaller the mass of the substance being dissolved, the smaller the solubility and the larger the K_{sp} . Any mass difference should not affect the K_{sp} value of silver chloride. Students' understanding of the basic concepts of solubility and K_{sp} could be better, especially the question of presenting a microscopic representation of salt (AgCl), which requires students to have a higher understanding of the concept. A correct understanding of basic concepts is necessary to understand higher concepts ([Adawiyah, 2017](#)).

Student misconception data in question number 8 was identified at 22.05%. Students are asked to calculate the solubility and choose which of silver bromide, silver chloride, silver iodate, and silver carbonate is the saturated solution. Students' errors in using the formula for calculating the solubility of silver bromide are the cause of misconceptions. Apart from that, students need to be more careful and pay attention to the concentration range of solubility of silver ions that meets the requirements for a compound to be in the saturated solution phase, namely 10^{-7} - 10^{-6} mol/L.

5. Effect of the same ion on solubility (questions number 9 and 10)

Misconceptions experienced by students in question number 9 were found to be 20.75%. Students are asked to conclude a graph of the solubility of magnesium fluoride in sodium fluoride solution. The graph displays data on magnesium fluoride's solubility and sodium fluoride's concentration. A solubility vs concentration graph in the question makes it difficult for most students to understand the relationship between them. Students also misunderstand that adding similar ions will increase the solubility and shift the equilibrium to the right. The correct answer is the opposite: the solubility decreases, and the equilibrium shifts to the left.

The percentage of student misconceptions in question number 10 is 25.75%. Students are asked to determine the smallest solubility of barium sulfate if a compound containing the same ion is added. Students make the mistake of choosing compounds that contain similar ions and their concentration values, so they mistakenly calculate the solubility from the concentration and K_{sp} values, which are known to be a factor in misconceptions. Students' low understanding of this concept is related to their low understanding of the concept of chemical equilibrium. This is by the results of research ([Sudiana et al., 2019](#)) which states that students who need help understanding the concept of chemical equilibrium will have difficulty understanding the concept of the influence of the same ion on solubility.

6. Effect of pH on solubility (questions number 11 and 12)

Student misconception data on question number 11 is known to be 27.5% and is one of the highest misconceptions of all question items. Students are asked to determine the most excellent solubility of calcium carbonate in acidic or basic solutions based on solubility graphs with various pH values. This high level of misconception results from students not being used to interpreting graphs, so they misread the graph of the relationship between CaCO_3 and pH solubility. Students need to understand the concept of previous material related to the solubility of salts in weak acids and weak bases and strong acids and strong bases. Apart from that, students' low understanding

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of the relationship between pH and solubility is caused by not mastering how to use and solve the formula for calculating acid-base pH.

In question number 12, it is known that student misconceptions are 25.75%. Students are asked to determine which salt will dissolve if a saturated solution of silver phosphate, silver sulfate, and silver chloride is added to nitric acid. Students need to understand the salt types and the acid effect when added to certain salt wells. Most students think that adding acid does not affect the solubility of the salt. Misconceptions in this sub-concept are caused by students' low understanding of the relationship between K_{sp} and pH values, weak calculation skills, and lack of strength in basic chemistry concepts such as acid-base reaction equations ([Sudiana et al., 2019](#)).

7. Estimate the formation of precipitates based on Q_c and K_{sp} values (questions 13, 14 and 15)

Student misconceptions in question number 13 are known to be 27%. Students are asked to estimate the reaction results between sodium iodide solution and lead nitrate. Students need help choosing the formula used to determine the presence or absence of sediment. Apart from that, when determining the Q_c and K_{sp} values, students also made the wrong comparison, so they needed to be corrected in determining what compound precipitate was formed.

Data on student misconceptions in question number 14 is known to be 21.5%. Students are asked to calculate and conclude the reactions that can produce lead chromate precipitates from a mixture of potassium chromate and lead nitrate with various concentrations. This sub-concept has complex calculations, making it quite difficult for students to predict whether or not a precipitate will form from the reaction of mixing substances. This is also thought to cause students to experience difficulties and result in misconceptions.

In the last question, question number 15, student misconceptions were found to be 27% and was one of the questions with the highest percentage of misconceptions apart from question number 11. Students were asked to calculate and conclude the reaction results between samples containing Fe^{2+} and Pb^{2+} ions and oxalic acid. Students need to differentiate and calculate Q_c and K_{sp} values; calculation errors will result in wrong conclusions when determining which compound precipitates. Students also assume sediment will occur if the K_{sp} value $>$ Q_c value. The research results ([Sudiana et al., 2019](#)) also state that students need to fully understand this concept regarding the concentration of ions from a mixture of two solutions, are confused about differentiating K_{sp} and Q_c , and need help applying mathematical knowledge.

Conclusion

This research concludes that the misconceptions experienced by the class research results are essential and helpful in preventing continued misconceptions regarding other chemical materials. This cannot be separated from one of the characteristics of chemical materials: sequential and interrelated. So that educators can map concepts that have the potential to cause misconceptions and can provide special treatment for classroom learning. It is possible to develop similar follow-up research

to sharpen the analysis results and to discover the causes of misconceptions more deeply. Suggestions for future research are diagnostic questions that are developed in more detail to identify sub-concepts that have the potential to give rise to misconceptions. So, the cause of misconceptions can be known with certainty and become initial knowledge to prevent future misconceptions.

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