JPPIPA 12(10) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Fostering SDG 4 Quality Education: Diagnostic Assessment of Grade 10 Students' Stoichiometry Difficulties in the Merdeka Curriculum

Trian Zulfa[1*], Erlina[1], Ira Lestari[1], Eny Enawaty[1], Maria Ulfah[1]

[1] Department of Mathematics and Natural Science Education, Faculty of Teacher Training and Education, Tanjungpura University, Pontianak 78124, Indonesia.

Received: January 6, 2026
Revised: October 5, 2026
Accepted: October 26, 2026
Published: October 31, 2026

Corresponding Author:
Trian Zulfa
f1061201033@student.untan.ac.id

DOI: 10.29303/jppipa.v12i10.14192

Open Access

© 2026 he Authors. This article is distributed under a (CC-BY License)

Abstract: In alignment with Sustainable Development Goal 4 (SDG 4) for quality education and the demands of Indonesia's Merdeka Curriculum, mastering stoichiometry in Phase E is crucial, yet students frequently struggle with its combined conceptual and quantitative demands. This study aims to investigate students' learning difficulties in stoichiometry, focusing on challenging concepts and their underlying contributing factors. Using a quantitative descriptive approach, the research involved 26 Class X-K students at SMA Negeri 1 Pontianak. Data were collected using a three-tier diagnostic test and follow-up interviews. The results revealed that 75.13% of students demonstrated non-scientific conceptions, predominantly characterized by misconceptions and a lack of conceptual knowledge in stoichiometry. The highest difficulty rates occurred in stoichiometric calculations (90.50%) and substance concentration (83.00%), followed by empirical and molecular formulas (77.00%), while the mole concept showed a moderate difficulty rate of 50.00%. These difficulties stemmed from internal factors specifically low learning motivation, weak conceptual understanding, and inadequate mathematical skills as well as external factors related to instructional methods. In conclusion, calculation-intensive topics present the primary barrier to mastering stoichiometry, emphasizing the urgent need for pedagogical interventions that integrate mathematical reinforcement and student-centered learning strategies to support meaningful learning outcomes.

Keywords: Learning Difficulties; Stoichiometry Material; Three-Tier Diagnostic Test

Introduction

Quality education requires learning processes that enable students to achieve meaningful and effective outcomes, aligning with Sustainable Development Goal 4 (SDG 4) and Target 4.1 on inclusive and equitable education. Achieving these outcomes requires identifying barriers to student learning. In classroom contexts, assessment practices play a vital role in revealing student understanding and learning difficulties, with research showing that formative assessment positively contributes to learning when used to address students' specific needs (Karaman, 2021; Sortwell et al., 2024).

In science education, chemistry requires coordinating conceptual, representational, and quantitative knowledge. This demand is particularly evident in stoichiometry, where students must connect substance amounts, masses, particle numbers, gas volumes, and chemical equations. Consequently, success in stoichiometry depends on both conceptual understanding and the meaningful application of mathematical relationships, rather than rote memorization.

Research demonstrates that the combined mathematical and conceptual demands of stoichiometry

How to Cite:
Zulfa, T., Erlina, E., Lestari, I., Enawaty, E., & Ulfah, M. (2026). Fostering SDG 4 Quality Education: Diagnostic Assessment of Grade 10 Students' Stoichiometry Difficulties in the Merdeka Curriculum. *Jurnal Penelitian Pendidikan IPA*, *12*(10), 221–234. https://doi.org/10.29303/jppipa.v12i10.14192

create substantial learning hurdles. Rosa & Lewis (2019) found that lower mathematical aptitude exacerbated difficulties with the mole concept and stoichiometry. Crucially, these difficulties stem not just from computational errors, but from struggles to conceptualize the underlying chemical algorithms and relationships.

Furthermore, students often learn stoichiometry as procedural calculations without understanding the underlying chemical reactions. Rosa et al. (2022) observed that mole and stoichiometric conversions dominate introductory chemistry assessments and strongly predict future exam performance. However, their qualitative data revealed that students frequently treat stoichiometry merely as step-by-step procedures, highlighting the risk of reproducing correct algorithms without conceptual understanding.

Similar challenges exist within Indonesian secondary education. Lestari et al. (2021) identified a 44.6% overall misconception rate in stoichiometry using a three-tier diagnostic test across basic chemical laws, molar mass, molar volume, and limiting reagents. By combining diagnostic data with interviews, they emphasized the need to examine incorrect responses to understand student reasoning.

Stoichiometric difficulties are also influenced by specific cognitive and instructional factors. Rather than relying on broad categories, relevant factors include numerical ability, prior conceptual knowledge, information interpretation, problem-solving skills, motivation, and learning experiences. In Grade 10 contexts, Allo & Azrun (2023) confirmed that learning difficulties stem from low numerical ability, material interpretation issues, limited prior knowledge, low motivation, and external learning conditions.

Addressing these issues requires tools beyond conventional test scores, which fail to reveal students' reasoning or confidence levels. Diagnostic instruments like the three-tier diagnostic test—evaluating conceptual answers (tier 1), underlying reasons (tier 2), and confidence levels (tier 3) provide deeper insights into student misconceptions (Ekawisudawati et al., 2021; Lestari et al., 2021).

Using diagnostic assessment supports broader educational quality goals. Meta-analyses by Karaman (2021) and Sortwell et al. (2024) confirm that formative and diagnostic practices generally exert positive effects on learning by identifying student needs to guide responsive instruction, directly advancing SDG 4 objectives.

This approach is highly relevant to Indonesia's Merdeka Curriculum, which emphasizes *Capaian Pembelajaran* (learning outcomes) across developmental phases. Fitri & Adiwinata (2026) noted that stoichiometry is a foundational Phase E (Grade 10) concept that provides the quantitative basis for Phase F topics like thermochemistry, reaction rates, and electrochemistry. Unresolved difficulties at Grade 10 can thus hinder future chemistry learning.

The current curriculum demands a shift from formulaic memorization to scientific reasoning. As Rosa et al. (2022) highlighted, procedural success alone does not ensure conceptual understanding. Assessments must evaluate whether students truly grasp the chemical relationships behind their calculations.

Preliminary observations with a chemistry teacher at SMA Negeri 1 Pontianak confirm local relevance: Grade 10 students struggle with the mole concept, empirical/molecular formulas, percentage composition, and selecting correct procedures. These issues suggest difficulties in bridging conceptual knowledge with quantitative methods, necessitating systematic diagnosis.

Although previous studies examined misconceptions and learning factors, gaps remain. Existing studies employ varied constructs (e.g., aptitude vs. conceptual understanding) that limit direct comparisons. Furthermore, novelty cannot rest solely on using three-tier tests or interviews, as these techniques are already established (Allo & Azrun, 2023 ; Lestari et al., 2021).

Instead, this study extends prior research by providing a contextualized diagnostic analysis of Grade 10 stoichiometry difficulties under the Merdeka Curriculum and linking identified patterns to underlying learning factors. By positioning diagnostic assessment as a driver for responsive teaching and connecting foundational Phase E concepts to SDG 4 goals, this research integrates curriculum context, diagnostic evidence, and contributing factors.

Accordingly, this study aims to map stoichiometric difficulties and investigate their contributing factors among Grade 10 students at SMA Negeri 1 Pontianak under the Merdeka Curriculum. Using a three-tier diagnostic test and qualitative interviews, the study seeks to generate empirical insights to guide responsive chemistry instruction and support meaningful learning outcomes in line with SDG 4.

Method

The type of research used in this study is quantitative descriptive. The research was conducted at SMA Negeri 1 Pontianak during the even semester of the 2023/2024 academic year. The subjects of this study were 26 Class X students from SMA Negeri 1 Pontianak, a school that implements the Merdeka Curriculum. The research procedure and data collection flow are illustrated in Figure 1.

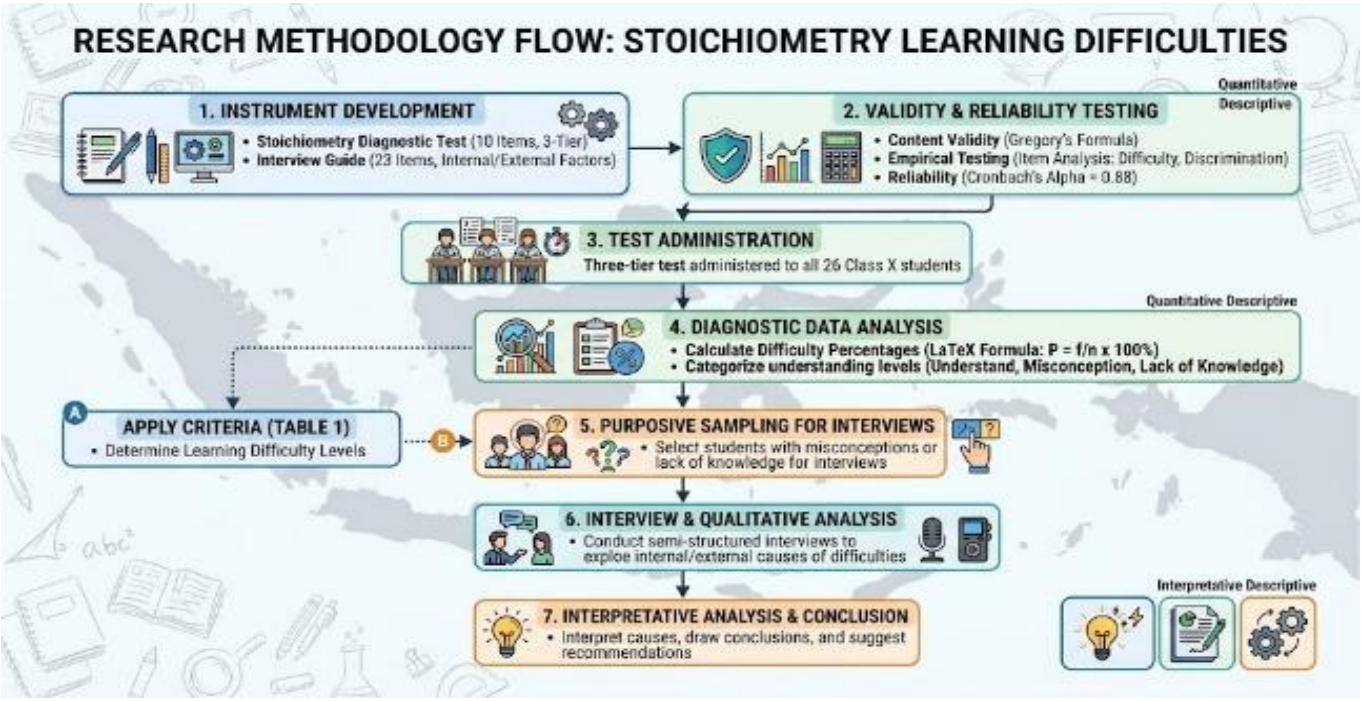


Figure 1. Research Procedure Flowchart

This study employed two data collection techniques: measurement and direct communication. The measurement technique utilized a three-tier diagnostic test, administered simultaneously to all 26 Class X students over a one-hour period. The direct communication technique involved semi-structured interviews conducted after the diagnostic test results were fully analyzed. As defined by Sugiyono (2013), these interviews allowed students to respond freely while staying within the predefined thematic guidelines.

The three-tier diagnostic test consists of 10 multiple-choice questions with reasoning. The first tier includes questions about stoichiometry concepts, the second tier contains students' reasons for their answers in the first tier, and the third tier assesses students' single combined confidence level regarding the correctness of their first-tier answer and second-tier reasoning. Recent literature supports the implementation of multi-tier diagnostic instruments to evaluate students' conceptual understanding and identify misconceptions; a systematic review revealed that three-tier diagnostic tests are the most widely utilized format across the reviewed chemistry studies (Damsi & Suyanto, 2023).

The diagnostic test was designed to assess stoichiometry concepts aligned with the Class X Merdeka Curriculum (CP/ATP) at SMA Negeri 1 Pontianak. Prior to administration, it underwent content validation using Gregory's formula based on expert judgments. In addition, an empirical trial was conducted to evaluate item quality through Item Analysis, which included the Difficulty Index (I) and Discriminating Power (D), ensuring all items met standard pedagogical criteria before field administration. Test reliability was confirmed using SPSS via Cronbach's Alpha ($\alpha = 0.88$), indicating high internal consistency. This diagnostic approach aligns with recent studies demonstrating that diagnostic tools effectively identify misconceptions and conceptual difficulties in science education, particularly research utilizing multi-tier tests and curriculum-aligned content (Kartimi et al., 2021; Shiddiqi et al., 2024).

Data regarding the internal and external causes of learning difficulties were gathered using a validated interview guide. The guide contained 23 pre-determined questions covering internal factors (11 items on physical, psychological, and fatigue aspects) and external factors (10 items on family, school, and community aspects). The content validity of the interview guide was evaluated and confirmed using Gregory's formula. Unlike the diagnostic test which was given to all 26 students, the interviews were conducted using purposive sampling. Only students who met the criteria for having misconceptions or lacking conceptual understanding (based on Table 2) were selected for interviews to explore the underlying causes of their difficulties. Combining diagnostic testing with interviews is supported by recent research in which qualitative interviews were conducted to investigate the factors underlying students' misconceptions following the administration of diagnostic tests (Pratiwi et al., 2023; Arini et al., 2025).

The data analysis techniques used in this study include descriptive statistical analysis and interpretative descriptive analysis. Descriptive statistical analysis was

(1)

used to determine the percentage of students' learning difficulties in stoichiometry concepts. The percentage calculation was performed using Formula 1.

$$P = \frac{f}{n}\ x\ 100\% \quad (1)$$

Where:
P = percentage of students experiencing learning difficulties (%)
f = frequency of students providing incorrect answers or demonstrating misconceptions
n = total number of participating students ($n = 26$)

After obtaining the percentage results, they were categorized according to the learning difficulty criteria presented in Table 1.

Table 1. Criteria for Learning Difficulties

Percentage (%)	Criteria
1 - 20	Not difficult
21 – 40	Slightly difficult
41 – 60	Moderately difficult
61 – 80	Difficult
81 - 100	Very difficult

(Arikunto, 2013)

Interpretative descriptive analysis was used to identify the factors causing students' difficulties using the interview responses. Student classification prior to interview selection followed the standard grouping criteria for three-tier diagnostic tests outlined in Table 2. This analytical strategy is supported by empirical findings indicating that student misconceptions can be attributed to both internal factors, such as prior knowledge and reasoning, and external factors, such as instructional methods and learning resources (Pratiwi et al., 2023; Aliyah et al., 2025).

Table 2. Grouping Criteria for Students' Understanding Level

Tier I	Tier II	Tier III	Criteria/Category
Answer	Reason	Confidence	
True	True	Confident	Understand concept
True	True	Not confident	Lack of Knowledge / Unconfident
True	False	Not confident	Lack of Knowledge / Unconfident
False	True	Not confident	Lack of Knowledge / Unconfident
False	False	Not confident	Lack of Knowledge / Unconfident
True	False	Confident	Misconception
False	True	Confident	Misconception
False	False	Confident	Misconception

(Kurniawan, 2015)

Result and Discussion

This research was conducted at SMAN 1 Pontianak, a school implementing the *Merdeka* Curriculum where teachers incorporate differentiated learning in the classroom. A total of 26 Class X students participated in a 60-minute diagnostic session completing a three-tier diagnostic test based on stoichiometry learning indicators.

Identification of Students' Learning Difficulties in Stoichiometry

Based on the empirical data gathered from the three-tier diagnostic test, Class X students experienced varying levels of learning difficulties across all tested stoichiometry indicators. The overall summary of students' difficulty levels based on the standard classification criteria defined in the Methods section is presented in Table 3.

Table 3. Percentage and Difficulty Category of Students' Learning Difficulties in Stoichiometry

Stoichiometry Indicator / Concept	Percentage of Difficulty (%)	Category
Mole Concept	50.00%	Moderately Difficult
Empirical and Molecular Formulas	77.00%	Difficult
Percentage Composition	83.00%	Very Difficult
Stoichiometry & Limiting Reagents	90.50%	Very Difficult

As shown in Table 3, the level of learning difficulty spans from *Moderately Difficult* (50.00%) to *Very Difficult* (90.50%). These findings closely align with research by Ulfa (2019), which demonstrated that secondary students consistently face widespread difficulties across all evaluated stoichiometry sub-concepts.

Recent chemistry education research similarly shows that stoichiometry remains a high-demand area because students often approach mole and stoichiometric conversions procedurally rather than connecting calculations to chemical meaning. Rosa et al. (2022) found that stoichiometric conversions were among the most frequently assessed competencies and that students commonly treated stoichiometry as a sequence of calculations disconnected from the chemical reaction. More recent diagnostic research also continues to report substantial misconceptions in chemistry and emphasizes the value of systematic diagnostic assessment for identifying students' conceptual barriers (Damsi & Suyanto, 2023; Rokhim et al., 2023 ; Shiddiqi et al., 2024).

1. *Difficulty in the Mole Concept (Moderately Difficult – 50.00%)*

The mole concept incorporates fundamental sub-concepts, including determining the mass of a compound, the number of molecules, and the molar volume of gases.

1) Sub-concept: Mass of a Compound

Students struggled primarily with translating descriptive chemical problems into balanced chemical equations. In Figure 2, students failed to identify reactants ($C_6H_{12}O_6$) and products (C_2H_5OH and CO_2) correctly, leaving the equation unbalanced.

These errors are consistent with recent evidence that students can have difficulty translating verbal chemical information into equations and quantitative relationships. Studies of chemical calculations and stoichiometry have highlighted the importance of linking symbolic representations, proportional reasoning, and the underlying chemical process rather than treating calculations as isolated procedures (Stott, 2021; Rosa et al., 2022; Díaz & Aizman, 2023). Previous studies highlights the importance of connecting chemical symbolic representations with students' conceptual interpretations. Martini (2021) examined students' ability to identify these symbolic representations, providing a relevant basis for understanding errors in translating chemical descriptions and equations.

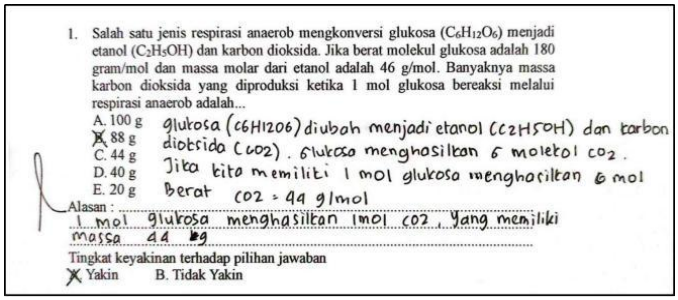


Figure 2. Difficulty in the Sub concept of Mass of a Compound

Furthermore, as illustrated in Figure 3 and Figure 4, another persistent error occurred during mass calculation. Students failed to compute the compound's mass because of conceptual confusion regarding molar mass (M_r). To calculate the mass of a substance correctly, students must determine the relative molecular mass (M_r) of the compound and multiply it by the number of moles obtained from the balanced chemical equation. Instead, students confused the relative molecular mass (M_r) with the molecular formula itself.

Recent work on the mole concept also indicates that students' difficulties are partly conceptual: inconsistent explanations of the mole can obscure the distinction between amount of substance, the mole as a unit, and numerical particle counts (Rees & Bruce, 2022). In addition, Raviolo et al. (2021) reported that students may rely on algorithmic numerical strategies while lacking a clear conceptual understanding of quantitative relationships. Studies on chemistry learning materials similarly indicate that the limited integration of multiple representations can impede understanding at the molecular level (Sundari et al., 2021). This underscores the necessity of bridging particle-level concepts with quantitative mole calculations.

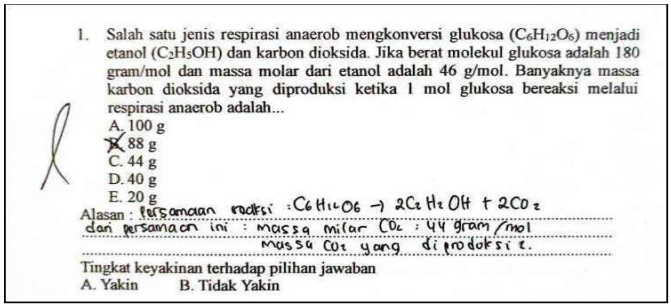


Figure 3. Difficulty in the Sub concept of Mass of a Compound

In addition, students failed to recognize that stoichiometric coefficients in a balanced equation represent mole ratios. These findings corroborate the results of Krisnawati & Fajaroh (2013), who reported that secondary students exhibit a poor conceptual understanding of fundamental mole-mass relationships.

Recent research reinforces the importance of understanding coefficients as quantitative relationships rather than merely as numbers used in a calculation. Studies of stoichiometric problem solving have documented errors involving mole ratios, proportional reasoning, and the interpretation of coefficients, including evidence that even teachers can exhibit inconsistent reasoning about mole ratios (Stott, 2021).

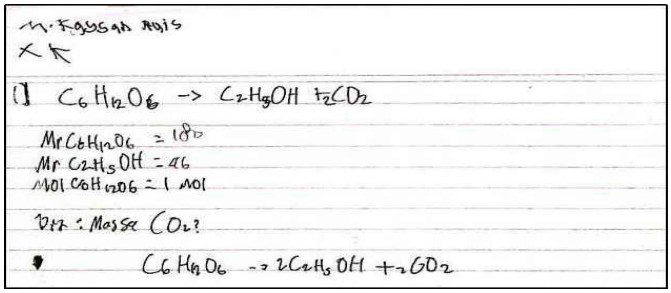


Figure 4. Difficulty in the Sub concept of Mass of a Compound

2) Sub-concept: Number of Molecules of a Compound

The difficulty in calculating the number of molecules stems from two major issues: failure to balance equations (Figure 5) and misinterpretation of Avogadro's constant.

Difficulty with particle-number calculations can also be interpreted through students' developing understanding of the mole as a bridge between macroscopic and submicroscopic descriptions. Recent research emphasizes that the mole concept is difficult when students do not clearly connect amount of substance, Avogadro's constant, particle number, mass, and other representations (Rees & Bruce, 2022; Raviolo et al., 2021).

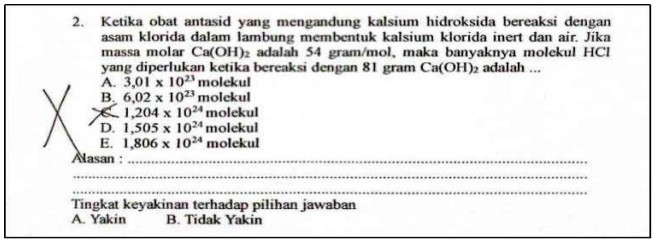

2. Ketika obat antasid yang mengandung kalsium hidroksida bereaksi dengan asam klorida dalam lambung membentuk kalsium klorida inert dan air. Jika massa molar $Ca(OH)_2$ adalah 54 gram/mol, maka banyaknya molekul HCl yang diperlukan ketika bereaksi dengan 81 gram $Ca(OH)_2$ adalah ...
A. 3,01 x 10^{23} molekul
B. 6,02 x 10^{23} molekul
C. 1,204 x 10^{24} molekul
D. 1,505 x 10^{24} molekul
E. 1,806 x 10^{24} molekul
Alasan : .....
Tingkat keyakinan terhadap pilihan jawaban
A. Yakin B. Tidak Yakin

Figure 5. Difficulty in the Sub concept of Number of Molecules of a Compound

In Figure 6, an order-of-magnitude and decimal format error was identified. Students incorrectly wrote Avogadro's constant without proper decimal notation (writing 6022×10^{23} instead of 6.022×10^{23}), causing significant errors in subsequent exponential calculations.

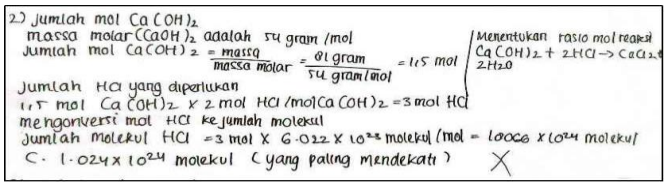

2.) Jumlah mol $Ca(OH)_2$
massa molar $(Ca(OH)_2$ adalah 54 gram/mol
Jumlah mol $Ca(OH)_2$ = massa / massa molar = 81 gram / 54 gram/mol = 1,5 mol
Menentukan rasio mol reaksi
$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$
Jumlah HCl yang diperlukan
1,5 mol $Ca(OH)_2$ x 2 mol HCl / mol $Ca(OH)_2$ = 3 mol HCl
mengonversi mol HCl ke jumlah molekul
Jumlah molekul HCl = 3 mol x 6.022×10^{23} molekul / mol = $1,0024 \times 10^{24}$ molekul
C. 1.024×10^{24} molekul (yang paling mendekati)

Figure 6. Difficulty in the Sub concept of Number of Molecules of a Compound

In Figure 7, students exhibited mathematical formula misapplication; after obtaining the mole values, they raised the mole value to the power of the stoichiometric coefficient instead of multiplying the mole value by the coefficient and Avogadro's number (6.022×10^{23} molecules/mol). This behavior reflects a weak mathematical foundation and reliance on rote memorization rather than conceptual understanding (Anggraini, 2013; Alkadrie, 2013).

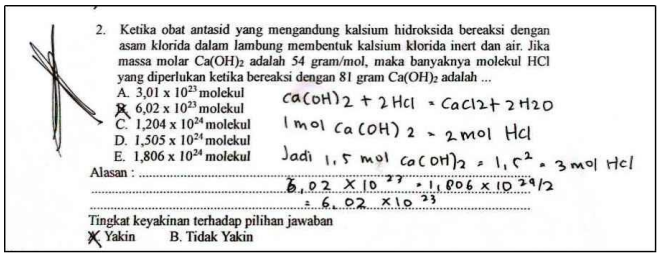

2. Ketika obat antasid yang mengandung kalsium hidroksida bereaksi dengan asam klorida dalam lambung membentuk kalsium klorida inert dan air. Jika massa molar $Ca(OH)_2$ adalah 54 gram/mol, maka banyaknya molekul HCl yang diperlukan ketika bereaksi dengan 81 gram $Ca(OH)_2$ adalah ...
A. 3,01 x 10^{23} molekul
B. 6,02 x 10^{23} molekul
C. 1,204 x 10^{24} molekul
D. 1,505 x 10^{24} molekul
E. 1,806 x 10^{24} molekul
$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$
1 mol $Ca(OH)_2$: 2 mol HCl
Jadi 1,5 mol $Ca(OH)_2$ = $1,5^2$ = 3 mol HCl
$6,02 \times 10^{23} \times 1,806 \times 10^{24}/2$
$= 6,02 \times 10^{23}$
Alasan : .....
Tingkat keyakinan terhadap pilihan jawaban
Yakin B. Tidak Yakin

Figure 7. Difficulty in the Sub concept of Number of Molecules of a Compound

3) Sub-concept: Molar Volume of a Compound

As shown in Figure 8 and Figure 9, student difficulties in molar volume calculations are linked to the Stoichiometry of Combustion Reactions. In Figure 7, students failed to balance the oxygen (O_2) atoms when formulating the combustion equation of butane gas (C_4H_{10}).

Recent studies continue to identify stoichiometry as a concept that benefits from explicit connections among chemical equations, quantities, and representations. Haelermans (2022) for example, reported improved success in mass–mass stoichiometry when students were supported with an approach emphasizing scale, proportion, and quantity, suggesting that the structure of quantitative reasoning matters for students' performance. Additionally, Anzalina et al. (2024) highlighted that interweaving mathematical concepts with chemistry instruction affects student interest and creates learning hurdles. This provides a clear rationale for investigating mathematical demands alongside chemical understanding within the context of stoichiometry.

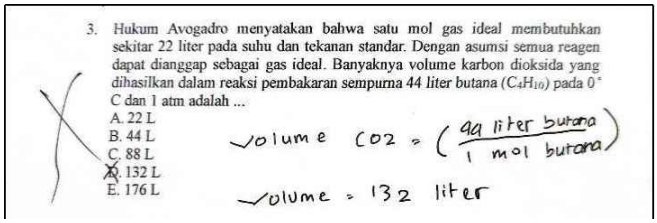

3. Hukum Avogadro menyatakan bahwa satu mol gas ideal membutuhkan sekitar 22 liter pada suhu dan tekanan standar. Dengan asumsi semua reagen dapat dianggap sebagai gas ideal. Banyaknya volume karbon dioksida yang dihasilkan dalam reaksi pembakaran sempurna 44 liter butana (C_4H_{10}) pada 0° C dan 1 atm adalah ...
A. 22 L
B. 44 L
C. 88 L
D. 132 L
E. 176 L
Volume CO_2 = (6 mol butana / 1 mol butana)
Volume = 132 liter

Figure 8. Difficulty in the Sub concept of Molar Volume of a Compound

In Figure 9, extreme computational errors were observed (e.g., calculating 1964 moles instead of 2 moles from a volume of 44 L). This highlights severe deficiencies in basic arithmetic operations and algebraic manipulation under exam conditions.

Such errors should not be interpreted solely as arithmetic failures because quantitative chemistry problems often require students to coordinate mathematical operations with chemical meanings. Research on chemistry problem solving indicates that fragmented mathematical and chemical knowledge can make multi-step calculations particularly difficult (Iwuanyanwu, 2021 ; Vo et al., 2022).

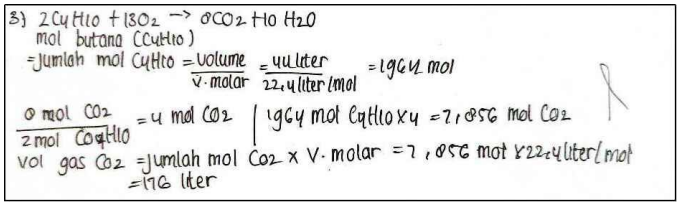

3) $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$
mol butana (C_4H_{10})
= jumlah mol C_4H_{10} = volume / V. molar = 44 liter / 22,4 liter/mol = 1964 mol
8 mol CO_2 / 2 mol C_4H_{10} = 4 mol CO_2 | 1964 mol $C_4H_{10} \times 4$ = 7,856 mol CO_2
vol gas CO_2 = jumlah mol CO_2 x V. molar = 7,856 mol x 22,4 liter/mol
= 176 liter

Figure 9. Difficulty in the Sub concept of Molar Volume of a Compound

2. *Difficulty in Empirical and Molecular Formulas (Difficult – 77.00%)*

The empirical and molecular formula indicator was categorized as *Difficult* (77.00%).

1) *Sub-concept: Empirical Formula*

As shown in Figure 10 and Figure 11, students failed to grasp the relationship between element mass percentages and mole ratios.

Recent research on stoichiometry also identifies empirical-formula reasoning as a persistent source of difficulty. Cai (2022) reported that students in a stoichiometry intervention continued to experience difficulty with empirical-formula calculations, while Karimatunnisa (2023) identified potential misconceptions in Indonesian high-school learning resources concerning empirical and molecular formulas, percentage composition, atomic and molecular mass, and chemical equations.

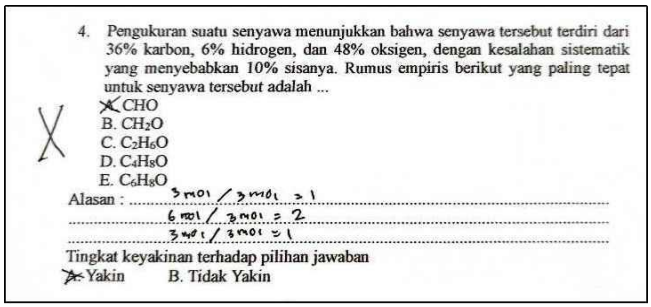

4. Pengukuran suatu senyawa menunjukkan bahwa senyawa tersebut terdiri dari 36% karbon, 6% hidrogen, dan 48% oksigen, dengan kesalahan sistematik yang menyebabkan 10% sisanya. Rumus empiris berikut yang paling tepat untuk senyawa tersebut adalah ...
X CHO
B. CH_2O
C. C_2H_6O
D. C_4H_8O
E. C_6H_8O
Alasan : 3 mol / 3 mol = 1
6 mol / 3 mol = 2
3 mol / 3 mol = 1
Tingkat keyakinan terhadap pilihan jawaban
X Yakin B. Tidak Yakin

Figure 10. Difficulty in the Sub concept of Empirical Formula of a Compound

Instead of converting elemental percentage abundances to mass and subsequently to moles, students oversimplified or miscalculated mole ratios due to incomplete mastery of prerequisite concepts (Arianto, 2015).

This pattern is consistent with the broader finding that students may have difficulty coordinating several linked representations in quantitative chemistry. Recent reviews of chemistry misconceptions emphasize that misconceptions can arise when students fail to integrate macroscopic, submicroscopic, and symbolic representations, making multi-step quantitative reasoning especially vulnerable to error (Rokhim et al., 2023; Munawwarah & Ashari, 2025).

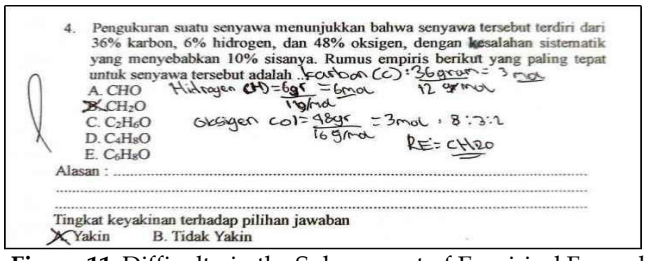

4. Pengukuran suatu senyawa menunjukkan bahwa senyawa tersebut terdiri dari 36% karbon, 6% hidrogen, dan 48% oksigen, dengan kesalahan sistematik yang menyebabkan 10% sisanya. Rumus empiris berikut yang paling tepat untuk senyawa tersebut adalah
A. CHO
X CH_2O
C. C_2H_6O
D. C_4H_8O
E. C_6H_8O
Karbon (C) = 36 gram = 3 mol
Hidrogen (H) = 6 gr = 6 mol
Oksigen (O) = 48 gr = 3 mol
RE: CH_2O
Alasan :
Tingkat keyakinan terhadap pilihan jawaban
X Yakin B. Tidak Yakin

Figure 11. Difficulty in the Sub concept of Empirical Formula of a Compound

2) *Sub-concept: Molecular Formula*

In Figure 12, Figure 13, Figure 14, and Figure 15, students demonstrated an inability to connect empirical formulas with molar mass derived from external constraints (such as the ideal gas equation $PV = nRT$). Many students stopped after finding the empirical formula (C_3H_6O) and failed to calculate the relative molecular mass (M_r) needed to derive the true molecular formula ($C_6H_{12}O_2$).

Recent work on chemical calculations likewise indicates that students can perform procedures without developing an integrated conceptual structure. Research on quantitative chemistry and problem solving emphasizes that meaningful performance requires students to coordinate formulas, representations, and conceptual reasoning rather than simply reproduce memorized procedures (Ginyigazi et al., 2024; Díaz & Aizman, 2023).

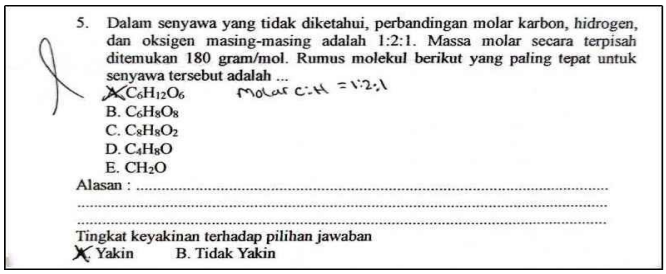

5. Dalam senyawa yang tidak diketahui, perbandingan molar karbon, hidrogen, dan oksigen masing-masing adalah 1:2:1. Massa molar secara terpisah ditemukan 180 gram/mol. Rumus molekul berikut yang paling tepat untuk senyawa tersebut adalah ...
X $C_6H_{12}O_6$ molar C:H = 1:2:1
B. $C_6H_8O_8$
C. $C_8H_8O_2$
D. C_4H_8O
E. CH_2O
Alasan :
Tingkat keyakinan terhadap pilihan jawaban
X Yakin B. Tidak Yakin

Figure 12. Difficulty in the Sub concept of Molecular Formula of a Compound

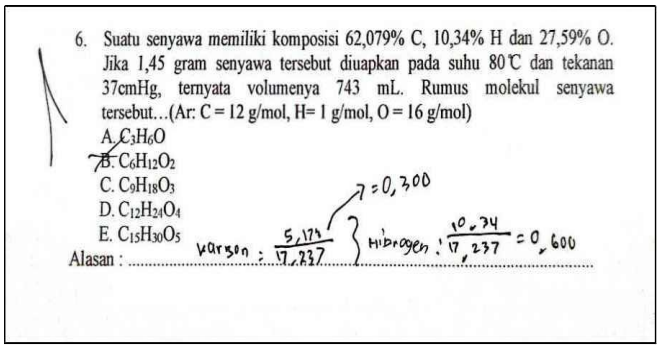

6. Suatu senyawa memiliki komposisi 62,079% C, 10,34% H dan 27,59% O. Jika 1,45 gram senyawa tersebut diuapkan pada suhu 80℃ dan tekanan 37cmHg, ternyata volumenya 743 mL. Rumus molekul senyawa tersebut...(Ar: C = 12 g/mol, H= 1 g/mol, O = 16 g/mol)
A. C_3H_6O
X B. $C_6H_{12}O_2$
C. $C_9H_{18}O_3$
D. $C_{12}H_{24}O_4$
E. $C_{15}H_{30}O_5$
Karbon : 5,174 / 17,237 = 0,300
Hidrogen : 10,34 / 17,237 = 0,600
Alasan :

Figure 13. Difficulty in the Sub concept of Molecular Formula of a Compound

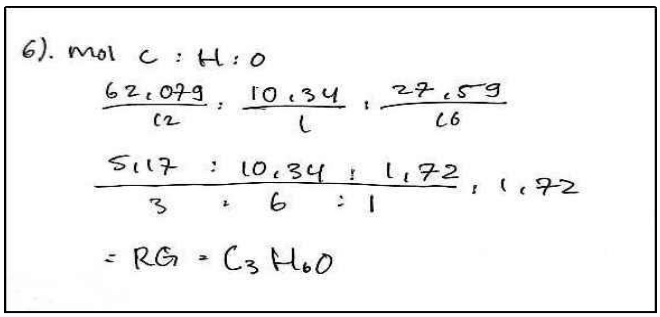

6). mol C : H : O
62,079 / 12 : 10,34 / 1 : 27,59 / 16
5,17 : 10,34 : 1,72 / 1,72
3 : 6 : 1
= RG = C_3H_6O

Figure 14. Difficulty in the Sub concept of Molecular Formula of a Compound

This failure to execute multi-step integrative problem-solving reflects fragmented knowledge structures, consistent with findings by Simangunsong & Pane (2021) and Krisnawati & Fajaroh (2013).

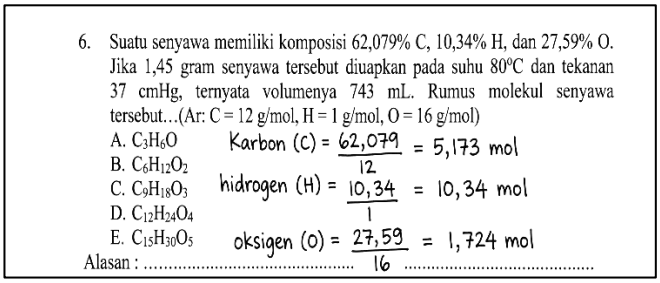


Figure 15. Difficulty in the Sub concept of Molecular Formula of a Compound

3. Difficulty in Percentage Composition (Very Difficult – 83.00%)

Percentage composition problems were categorized as *Very Difficult* (83.00%). The high difficulty observed here is consistent with recent literature showing that quantitative chemistry topics often combine conceptual and mathematical demands. Studies of molar concentration, volumetric analysis, and chemical calculations report that students can apply familiar formulas while still misunderstanding the quantities and relationships represented by those formulas (Raviolo et al., 2021; Clark et al., 2022; Rees & Bruce, 2022).

1) Sub-concept: Percentage by Volume

In Figure 16 and Figure 17, students struggled to integrate volumetric dilution concepts with percentage calculations.

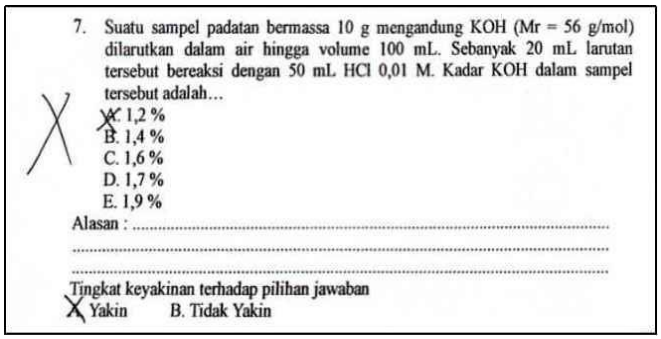


Figure 16. Difficulty in the Sub concept of Percentage by Volume

When presented with contextual multi-step problems involving titration or dilution prior to composition analysis, students applied incorrect formulas, demonstrating that their understanding is limited to simple algorithmic memorization.

This finding is particularly important because recent research suggests that students may adopt familiar heuristics even when those heuristics are inappropriate for the chemical context. Clark et al. (2022) found that students frequently used the M1V1 = M2V2 heuristic and often assumed a 1:1 molar ratio when solving volumetric-analysis problems, illustrating how procedural shortcuts can interfere with chemically appropriate reasoning.

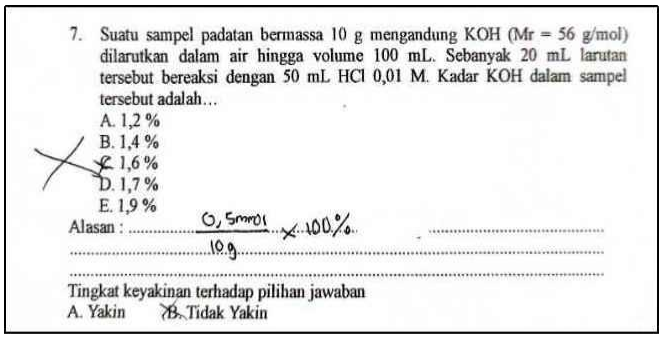


Figure 17. Difficulty in the Sub concept of Percentage by Volume

2) Sub-concept: Percentage by Mass

In Figure 18, Figure 19, and Figure 20, students displayed misconceptions regarding non-hydrocarbon combustion reactions (e.g., oxidation of sulfur to sulfur trioxide, $S + \frac{3}{2}O_2 \rightarrow SO_3$).

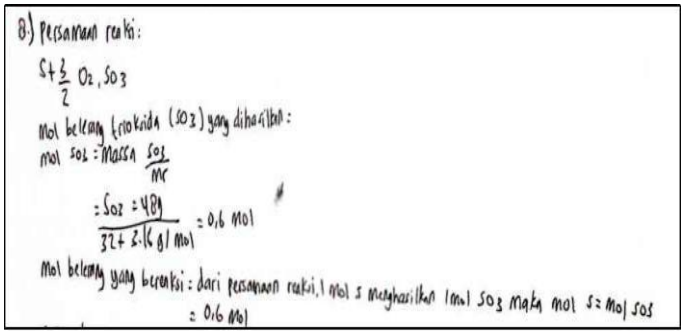


Figure 18. Difficulty in the Sub concept of Percentage by Mass

Furthermore, students mistakenly substituted basic mole formulas in place of mass percentage formulas ($\text{Mass \%} = \frac{\text{Mass of Element}}{\text{Mass of Sample}} \times 100\%$). These severe conceptual hurdles agree with observations by (Simangunsong & Pane, 2021).

Recent diagnostic research similarly shows that chemistry misconceptions can involve confusion among related quantities and formulas. Reviews of diagnostic studies emphasize that identifying the specific reasoning behind an incorrect response is important because a wrong answer alone cannot distinguish conceptual misunderstanding from calculation or procedural error (Damsi & Suyanto, 2023; Shiddiqi et al., 2024).

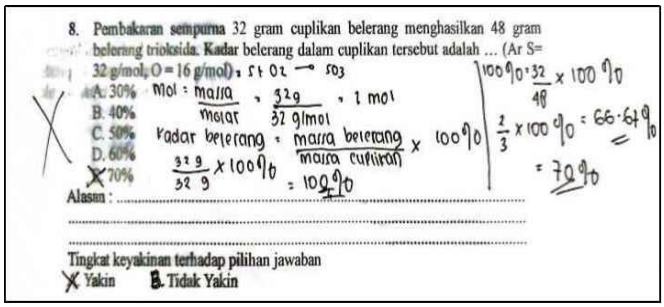


Figure 19. Difficulty in the Sub concept of Percentage by Mass

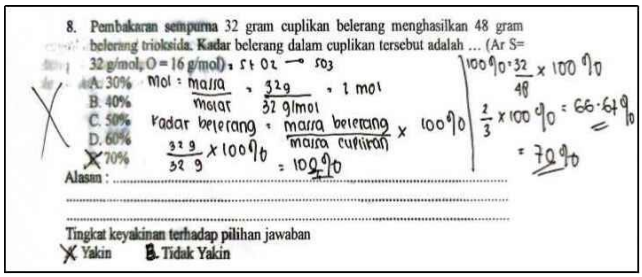


Figure 20. Difficulty in the Sub concept of Percentage by Mass

4. *Difficulty in Stoichiometry and Limiting Reagents (Very Difficult – 90.50%)*

The highest level of learning difficulty occurred in Stoichiometry and Limiting Reagents, reaching 90.50% (*Very Difficult*). The particularly high difficulty in limiting reagents is supported by recent research. Toledo et al. (2021) found that students' explanations of limiting reagents were associated with alternative conceptions and an algorithmic approach to teaching, while Edelsztein (2023) demonstrated that an experimental and representational approach can help students construct the limiting-reactant concept.

Sub-concept: Limiting Reagents and Solution Concentrations

As illustrated in Figure 21, Figure 22, Figure 23, Figure 24, Figure 25, and Figure 26, students exhibited fundamental misconceptions regarding limiting reactants. Limiting-reactant reasoning is especially demanding because students must compare reactants through stoichiometric relationships rather than simply select the substance present in the smallest or largest initial amount. Recent studies explicitly describe limiting reactant as a persistent difficulty among secondary and introductory chemistry students (Toledo et al., 2021 ; Edelsztein, 2023).

1) **Misconception of Consumption Rate:** In Figure 21 and Figure 22, students identified the limiting reagent as the reactant present in the largest quantity or the one that depletes the slowest, rather than the reactant that limits product formation based on mole-to-coefficient ratios.

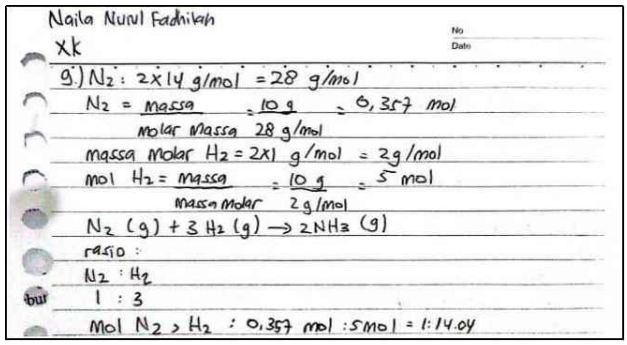


Figure 21. Difficulty in the Sub concept of Limiting Reagent

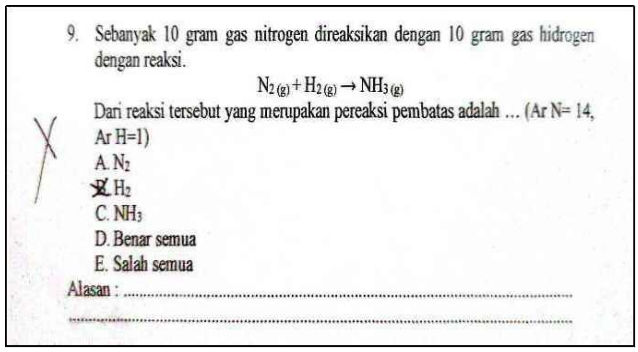


Figure 22. Difficulty in the Sub concept of Limiting Reagent

2) **Failure to Use ICF Tables:** In Figure 23, Figure 25, and Figure 26 students omitted Initial-Reacted-Final (ICF / ICF stoichiometry) tabulations, leading to errors in determining excess reactants and final concentrations (M) of products such as Na_2SO_4.

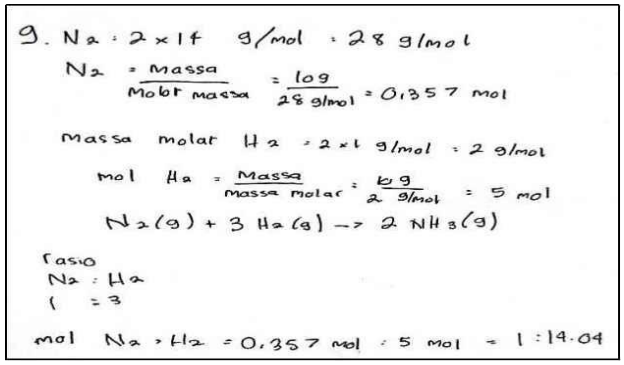


Figure 23. Difficulty in the Sub concept of Limiting Reagent

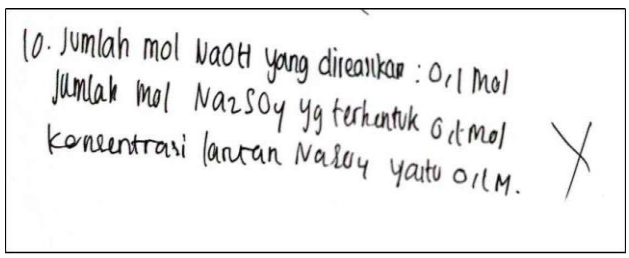


Figure 24. Difficulty in the Sub concept of Concentration of a Compound

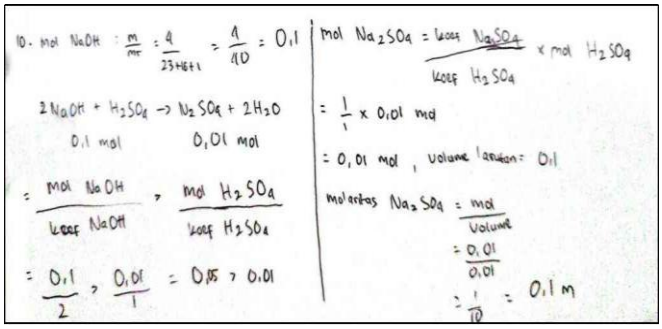


Figure 25. Difficulty in the Sub concept of Concentration of a Compound

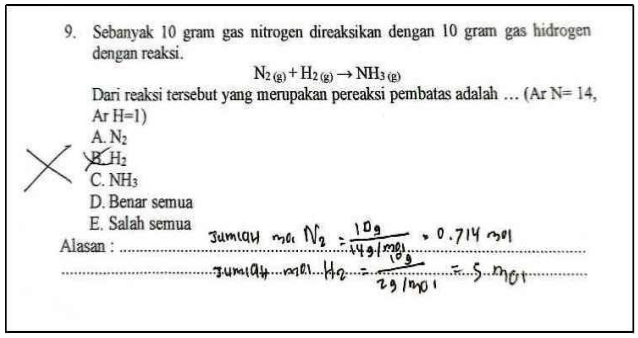


Figure 26. Difficulty in the Sub concept of Limiting Reagent

3) **Confusion between A_r and M_r:** In Figure 24, students used relative atomic mass (A_r) instead of relative molecular mass (M_r) when converting reactant masses into moles.

Analysis of Factors Causing Learning Difficulties

To understand the origin of these conceptual and mathematical hurdles, contributing factors were analyzed and categorized into internal and external dimensions, as summarized in Table 4.

Table 4. Description of Internal and External Factors Contributing to Students' Learning Difficulties

Factor Category	Aspect	Description of Contributing Factors
Internal	Physical	Lack of focus due to skipping breakfast prior to morning classes.
	Psychological	Low intrinsic motivation in learning chemistry, poor conceptual mastery of prerequisite topics, and low self-efficacy
	Mathematical Skills	Deficiencies in basic algebraic manipulations, decimal operations, fractions, and scientific notation handling.
	Fatigue	Physical and cognitive exhaustion following extracurricular activities.
	Family	Inadequate or non-conducive home study environment.
External	School / Pedagogical	Teacher-centered worksheet distribution lacking interactive scaffolding or conceptual explanation.
	Environmental	Lack of additional supplementary learning resources and peer environments that do not foster active academic collaboration

As detailed in Table 4, the primary drivers of student learning difficulties are psychological constraints, weak mathematical foundations, and pedagogical gaps. Environmental and physical factors play secondary roles.

Students frequently rely on short-term memorization for assessments rather than constructing deep conceptual schemas. This issue is compounded by weak mathematical fluency in working with decimals, ratios, and scientific notation (10^{23}).

This interpretation is consistent with recent research describing a persistent tension between algorithmic performance and conceptual understanding in chemistry. Rosa et al. (2022) reported that students often viewed stoichiometry as step-by-step calculation rather than as a way to reason about chemical reactions, while Cai (2022) similarly noted that students may attempt to memorize chemistry content without developing adequate conceptual understanding.

Implementation Gap in Differentiated Learning

An important finding of this study concerns the implementation of Differentiated Learning under the *Merdeka* Curriculum framework. Although SMAN 1 Pontianak officially mandates differentiated learning strategies, classroom observations and student interviews reveal a significant gap between curriculum policy and pedagogical practice.

Recent research on differentiated instruction indicates that effective differentiation requires more than assigning students independent tasks. Langelaan et al. (2024), in a review of differentiated-instruction teacher preparation, identified active learning, collaboration, reflection, and teacher knowledge and skills as important components, while Kahmann et al. (2022) showed that teachers' differentiation practices depend on how student needs are identified and monitored.

In practice, differentiated learning was frequently misinterpreted as unassisted independent learning. Teachers relied heavily on distributing independent worksheets (*LKPD*) without providing structured scaffolding, guided inquiry, or differentiated content tailored to students' baseline readiness levels.

This concern is also compatible with evidence that differentiation is not synonymous with removing teacher support. Kahmann et al. (2022) examined group differentiation in secondary schools and demonstrated

that students can require different degrees of instructional dependence; consequently, differentiation needs to be accompanied by deliberate decisions about the amount and type of support provided. The journal's scope includes science-learning assessment, misconceptions, curriculum, and instructional innovation, making these themes relevant to the present discussion.

Stoichiometry requires cognitive scaffolding to bridge abstract microscopic concepts (moles, molecules) with symbolic representations (chemical equations) and macroscopic calculations (mass, volume). When students are given worksheets without explicit instructional guidance, those with weak mathematical backgrounds or low intrinsic motivation experience heightened cognitive load and frustration.

Recent chemistry education studies provide direct support for the role of scaffolding in complex problem solving. Vo et al. (2022) reported that metacognitive scaffolding is relevant to chemistry problem solving, while Dood & Watts (2023) synthesized research showing that students' problem-solving strategies and struggles are strongly influenced by how they organize and interpret chemical information. In addition, digital and written task navigators have been developed as scaffolds to support students while solving chemistry problems (Schmidt et al., 2023). A study by Puspita Sari et al. (2026) showed that STEM-PBL thermochemistry resources were highly valid and practical, despite not measuring learning effectiveness. These findings support treating educational materials as supportive tools rather than conclusive evidence of overcoming learning obstacles.

Consequently, the failure to provide tiered instructional support within the differentiated learning framework exacerbated student reliance on formula memorization, ultimately worsening their conceptual errors in stoichiometry.

Recent evidence therefore suggests that diagnostic assessment should be connected to targeted instructional responses rather than used only to classify students. Multiple-tier diagnostic instruments are increasingly used to distinguish conceptual misunderstanding from lack of knowledge or uncertainty (Damsi & Suyanto, 2023 ; Simanjuntak et al., 2025), and recent reviews emphasize the continuing need to combine diagnosis with corrective teaching strategies (Shiddiqi et al., 2024; Pahriah et al., 2025).

Conclusion

Class X students at SMA Negeri 1 Pontianak experience learning difficulties in stoichiometry, with 75.13% of students demonstrating non-scientific conceptions (predominantly characterized by misconceptions and a lack of conceptual knowledge). The highest difficulty rates occur in stoichiometric calculations (90.50%) and substance concentration (83.00%), followed by empirical and molecular formulas (77.00%) as difficult concepts, while the mole concept shows a moderate difficulty rate of 50.00%. The factors causing these learning difficulties involve both internal and external factors. The primary internal factors include low motivation to learn chemistry, weak conceptual understanding of stoichiometry, and inadequate mathematical skills, while external factors are linked to the instructional methods applied by the teacher. Based on these findings, future research is recommended to focus on developing student-centered learning models integrated with mathematical reinforcement to reduce misconceptions. Additionally, further studies could explore targeted remedial programs to help students overcome specific calculation barriers in stoichiometry.

Acknowledgments

The authors would like to express their deepest gratitude to the Chemistry Education Study Program, Department of Mathematics and Natural Science Education, Faculty of Teacher Training and Education, Tanjungpura University, for their continuous support. Special thanks are extended to the thesis advisors and examiners for their insightful guidance, valuable suggestions, and constructive feedback throughout the completion of this research. The authors also extend their sincere appreciation to SMA Negeri 1 Pontianak, particularly the chemistry teachers and Class X students, for their invaluable cooperation and willingness to participate in this study.

Author Contributions

All authors have made a real contribution in completing this manuscript. T.Z. conceptualized the study, conducted the data collection and analysis, and drafted the original manuscript. E. and I.L., as primary supervisors, provided continuous guidance, supervised the research methodology, and critically revised the manuscript. E.E. and M.U., as examiners, evaluated the research validity, provided critical feedback on the diagnostic instruments and findings, and reviewed the final manuscript. All authors read and approved the final manuscript.

Funding

No external funding.

Conflicts of Interest

The authors declare no conflict of interest.

References

Aliyah, H., Fauzi, A., & Manaroh, M. A. (2025). Misconceptions, Diagnostic Instruments Used and Their Causes in Chemistry Learning: Literature

Review. *Jurnal Penelitian Pendidikan IPA*, *11*(11), 1–11. https://doi.org/10.29303/jppipa.v11i11.12581

Alkadrie, T. & S. B. (2013). *Analisis Pemahaman Konseptual dan Algoritmik pada Materi Kelarutan dan Hasil Kali Kelarutan*.

Allo, A. B., & Azrun, M. (2023). Analisis Faktor-Faktor Kesulitan Belajar Kimia Pada Materi Stoikiometri Kelas X Di Sma Negeri 1 Manokwari. *Chemistry Education Journal*, *6*(2), 541–546. https://doi.org/10.30862/accej.v6i2.554

Anggraini, F. & P. J. (2013). *Analisis Kesulitan Siswa Kelas XI IA SMA Negeri 1 Tanah Jawa dalam Menyelesaikan Soal-Soal Kelarutan dan Hasil Kali Kelarutan*.

Anzalina, H., Danika Pranata, O., Anzalina, H., Pranata, O. D., & Jurnal Penelitian Pendidikan, J. (2024). Analysis Students Interest In An Integrative Context: A Descriptive And Comparative Study In Chemistry Learning. *Jurnal Penelitian Pendidikan IPA (JPPIPA)*, *9*(2), 45–54. https://doi.org/https://doi.org/10.26740/jppipa.v9n2.p45-54

Arianto, A. (2015). Deskripsi Pemahaman Konsep Siswa pada Materi Kelarutan dan Hasil Kali Kelarutan Kelas IX IPA SMA. *Jurnal Pendidikan Kimia Universitas Tanjungpura*.

Arikunto. (2013). *Dasar - Dasar Evaluasi Pendidikan Edisi 3*. Bumi Aksara.

Arini, A. D., Azizah, U., Sukarmin, Satriawan, M., & Saphira, H. V. (2025). Analyzing Students' Misconceptions Based on Submicroscopic Level Representation in Elements, Compounds, and Mixtures. *Jurnal Penelitian Pendidikan IPA*, *11*(2), 25–34. https://doi.org/10.29303/jppipa.v11i2.10052

Ayu Lestari, E., Susilaningsih, E., & Nanik WIjayati, dan. (2021). Analisis Miskonsepsi Menggunakan Tes Diagnosa Three-Tier Multiple Choice Pada Materi Stoikiometri. In *Jurnal Inovasi Pendidikan Kimia* (Vol. 15, Number 2).

Cai, S. (2022). Harry Potter Themed Digital Escape Room for Addressing Misconceptions in Stoichiometry. *Journal of Chemical Education*, *99*(7), 2747–2753. https://doi.org/10.1021/acs.jchemed.2c00178

Clark, T., Dickson-Karn, N., & Anderson, E. (2022). Strategies Undergraduate Students Use to Solve a Volumetric Analysis Problem before and after Instruction. *Journal of Chemical Education*, *99*. https://doi.org/10.1021/acs.jchemed.2c00515

Damsi, M., & Suyanto, S. (2023). Systematic Literature Review: Multiple-tier Diagnostic Instruments in Measuring Student Chemistry Misconceptions. *Jurnal Penelitian Pendidikan IPA*, *9*(5), 8–21. https://doi.org/10.29303/jppipa.v9i5.2600

Díaz, B., & Aizman, A. (2023). Design and impact of a stoichiometry voluntary online course for entering first-year STEM college students. *Chemistry Education Research and Practice*, *25*(1), 11–24. https://doi.org/10.1039/d3rp00179b

Dood, A. J., & Watts, F. M. (2023). Students' Strategies, Struggles, and Successes with Mechanism Problem Solving in Organic Chemistry: A Scoping Review of the Research Literature. *Journal of Chemical Education*, *100*(1), 53–68. https://doi.org/10.1021/acs.jchemed.2c00572

Edelsztein, V. (2023). An Experimental Approach with a Twist: Helping High School Students to Understand the Concept of Limiting Reactant. *Journal of Chemical Education*, *100*(4), 1505–1510. https://doi.org/10.1021/acs.jchemed.2c00986

Ekawisudawati, E., Wijaya, M., & Danial, M. (2021). Analisis Miskonsepsi Peserta Didik pada Materi Asam Basa Menggunakan Instrumen Three-Tier Diagnostic Test. *Chemistry Education Review*, *5*(1), 2597. https://doi.org/10.26858/cer.v5i1.13315

Fitri, S., & Adiwinata, Y. (2026). Research and Practice of Educational Chemistry Analisis Struktur Materi Kimia dalam Kurikulum Merdeka Fase E dan F: Kajian Literatur (Analysis of the Structure of Chemistry Content in Phases E and F of the Merdeka Curriculum: A Literature Review). *Research and Practice of Educational Chemistry*, *5*(1), 10–23. https://doi.org/10.24235/respec.v5i01.24465

Ginyigazi, Z., Nqoma, L., Makena, B., & Mpiti, P. T. (2024). *Implementation of Conceptual Change Approach to Improve Learners' Understanding of Quantitative Chemistry Aspects*. https://doi.org/https://doi.org/10.5772/intechopen.114094

Haelermans, C. (2022). The Effects of Group differentiation by students' learning strategies. *Instructional Science*, *50*(2), 223–250. https://doi.org/10.1007/s11251-021-09575-0

Iwuanyanwu, P. N. (2021). Addressing common deficiencies of mathematics skills among chemistry student teachers. *African Journal of Educational Studies in Mathematics and Sciences*, *17*(1), 1–16. https://doi.org/10.4314/ajesms.v17i1.1

Kahmann, R., Droop, M., & Lazonder, A. W. (2022). Meta-analysis of professional development programs in differentiated instruction. *International Journal of Educational Research*, *116*. https://doi.org/10.1016/j.ijer.2022.102072

Karaman, P. (2021). The Effect of Formative Assessment Practices on Student Learning: A Meta-Analysis Study. *International Journal of Assessment Tools in Education*, *8*(4), 801–817. https://doi.org/10.21449/ijate.870300

Karimatunnisa. (2023). *Identifikasi Miskonsepsi Konsep Stoikiometri Pada Sumber Belajar Kimia Sma* (Vol. 8).

https://doi.org/https://doi.org/10.21831/jrpk.v8i2.20632

Kartimi, K., Yunita, Y., Fuadi, F. N., & Addiin, I. (2021). A Four-tier Diagnostic Instrument: An Analysis of Elementary Student Misconceptions in Science Topic. *Jurnal Penelitian Pendidikan IPA*, *7*(SpecialIssue), 61–68. https://doi.org/10.29303/jppipa.v7ispecialissue.1022

Krisnawati, I., & Fajaroh, F. (2013). Menggali Pemahaman Konsep Siswa Madrasah Aliyah tentang Stoikiometri dengan Menggunakan Instrumen Diagnostik Two-Tier. *Jurnal Kimia FMIPA Universitas Negeri Malang*, 1–7.

Kurniawan, Y. , & A. S. (2015). *The Three Tier-Test for Identification The Quantity of Students' Misconception on Newton's First Laws*.

Langelaan, B. N., Gaikhorst, L., Smets, W., & Oostdam, R. J. (2024). Differentiating instruction: Understanding the key elements for successful teacher preparation and development. In *Teaching and Teacher Education* (Vol. 140). Elsevier Ltd. https://doi.org/10.1016/j.tate.2023.104464

Martini, M. (2021). Analysis Of Students' Ability To Identify Symbolic Representations In Chemistry. *Jurnal Penelitian Pendidikan IPA (JPIPA)*, *6*(1), 7–10. https://doi.org/https://doi.org/10.26740/jppipa.v6n1.p7-10

Munawwarah, M., & Ashari, A. (2025). Unveiling Misconceptions in Chemistry: A Review of Causes, Common Patterns, and Levels of Student Understanding. *Jurnal Studi Guru Dan Pembelajaran*, *8*(3), 1765–1778. https://doi.org/10.30605/jsgp.8.3.2025.6935

Pahriah, Sudatha, I. G., Suartama, I. K., & Santosa, M. (2025). Students' Misconceptions in Chemistry Learning: A Systematic Literature Review from 2015 to 2025. *Hydrogen Jurnal Kependidikan Kimia*, *13*, 510–529. https://doi.org/10.33394/hjkk.v13i3.15805

Pratiwi, A. N., Erlina, E., Lestari, I., Masriani, M., & Rasmawan, R. (2023). Identification of Students' Misconceptions Using a Four-Tier Multiple Choice Diagnostic Test on Material Colligative Properties of Solutions. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 1–10. https://doi.org/10.29303/jjppipa.v1i1.264

Puspita Sari, D., Agustina Nst, M., Syafriani, D., Julian Pratiwi, A., Sari, D. P., Nst, M. A., Syafriani, D., Pratiwi, A. J., & Jurnal Penelitian Pendidikan, J. (2026). Validity And Practicality Of Stem-Pbl Based Thermochemistry Teaching Materials For Chemistry Education Students. *Jurnal Penelitian Pendidikan IPA (JPPIPA)*, *11*(1), 79–85. https://doi.org/https://doi.org/10.26740/jppipa.v11n1.p79-85

Raviolo, A., Farré, A., & Schroh, N. (2021). Students' understanding of molar concentration. *Chemistry Education Research and Practice*, *22*, 486–497. https://doi.org/10.1039/D0RP00344A

Rees, S. W., & Bruce, M. (2022). Inconsistent Language Use in Online Resources Explaining the Mole Has Implications for Students' Understanding. *Journal of Chemical Education*, *99*(7), 2446–2450. https://doi.org/10.1021/acs.jchemed.2c00199

Rokhim, D. A., Rahayu, S., & Dasna, W. (2023). Analisis Miskonsepsi Kimia dan Instrumen Diagnosisnya: Literatur Review. In *JIPK* (Vol. 17, Number 1). https://doi.org/https://doi.org/10.15294/jipk.v17i1.34245

Rosa, V., & Lewis, S. (2019). An explanative basis for the differential performance of students with low math aptitude in general chemistry. *Chemistry Education Research and Practice*, *20*, 570–593. https://doi.org/10.1039/C9RP00068B

Shiddiqi, M. H. A., Arthamena, V. D., Ayyubi, M., Manarisip, A. J., & Aznam, N. (2024). Systematic Literature Review: Analysis of Misconception Problems and Diagnostic Instruments for Learning Chemistry. *Jurnal Penelitian Pendidikan IPA*, *10*(4), 168–179. https://doi.org/10.29303/jppipa.v10i4.5189

Simangunsong, A. D. B., & Pane, E. P. (2021). Pengembangan Modul Kimia Dasar Berbasis Discovery Learning pada Materi Stoikiometri. *Jurnal Ilmu Pendidikan*, *3*(6), 4415–4425.

Simanjuntak, B. R. N., Wiji, W., & Widhiyanti, T. (2025). Systematic Literature Review: Three-Tier Diagnostic Test to Identifying Misconceptions in Chemistry. *Jurnal Penelitian Pendidikan IPA*, *11*(7), 37–47. https://doi.org/10.29303/jppipa.v11i7.11011

Sortwell, A., Trimble, K., Ferraz, R., Geelan, D. R., Hine, G., Ramirez-Campillo, R., Carter-Thuiller, B., Gkintoni, E., & Xuan, Q. (2024). A Systematic Review of Meta-Analyses on the Impact of Formative Assessment on K-12 Students' Learning: Toward Sustainable Quality Education. In *Sustainability (Switzerland)* (Vol. 16, Number 17). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/su16177826

Stott, A. E. (2021). South African physical sciences teachers' use of formulae and proportion when answering reaction-based stoichiometry calculation questions. *Chemistry Education Research and Practice*, *22*(2), 443–456. https://doi.org/10.1039/d0rp00291g

Sundari, I. D., Nurdiyanti, D., Yullina, I. K., Gusman, T. I., Sundari, I. D., Jurnal, J. (, & Pendidikan, P. (2021). The Design Of Electrolyte And Non Electrolyte Solution Teaching Materials With Multi

Representation. *Jurnal Penelitian Pendidikan IPA (JPPIPA)*, *6*(2), 75–80. https://doi.org/https://doi.org/10.26740/jppipa.v6n2.p75-80

Toledo, M. A. I., Lobos, J. I. M., Gatica, M. R. Q., Carrillo, Y. Y. C., & Melin, A. M. H. (2021). School explanations about the limiting reagent concept. *Educacion Quimica*, *32*(5), 81–95. https://doi.org/10.22201/fq.18708404e.2021.5.78128

Vanessa, R., States, N. E., Corrales, A., Nguyen, Y., & Atkinson, M. B. (2022). Relevance and equity: should stoichiometry be the foundation of introductory chemistry courses? *Chemistry Education Research and Practice*, *23*(3), 662–685. https://doi.org/10.1039/d1rp00333j

Vo, K., Sarkar, M., White, P. J., & Yuriev, E. (2022). Problem solving in chemistry supported by metacognitive scaffolding: teaching associates' perspectives and practices. *Chemistry Education Research and Practice*, *23*(2), 436–451. https://doi.org/10.1039/d1rp00242b