The influence of the application of mathematics on students' difficulties in solving chemical problems: A longitudinal study using national examination data

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Abstract. One indicator of students' mathematical mastery is their ability to apply mathematical concepts in science, such as chemistry. However, many students struggle when chemistry problems involve mathematical reasoning. This study aims to examine whether mathematical applications influence students' difficulty levels in solving chemistry problems. The research contribution is to provide empirical evidence on how mathematical applications relate to students' cognitive challenges in chemistry by integrating large-scale quantitative data with qualitative insights from teachers and experts. The study employed a descriptive–exploratory design using both quantitative and qualitative approaches. Quantitative data were drawn from Indonesia's national examination results (2013–2017), while qualitative data were collected through focus group discussions with three chemistry teachers and interviews with one chemistry education expert. Contingency-table analysis tested the effect of mathematical application on item difficulty, and thematic analysis identified causes of difficulty and teaching strategies. The findings show that mathematics does not significantly affect students' performance; rather, difficulties stem from the abstract and complex nature of chemistry concepts. Teachers overcome these challenges by using laboratories, visual media, and problem-solving exercises. These results suggest that conceptual understanding, rather than mathematical skill, is essential for improving chemistry learning and integrating mathematics with science education.no 8

1 Introduction

Mathematics, as we all know, is one of the branches of science that plays a crucial role in various aspects of life, particularly in the advancement of science, technology, and information. Numerous studies have demonstrated how mathematics is applied across diverse fields, including science [1], [2], medicine [3], [4], technology, and industry [5], [6]. Mathematics serves as a fundamental tool for representing, modeling, calculating, and predicting various quantitative relationships [7], [8] in efforts to solve a wide range of problems. It is even found in non-scientific domains such as art, business, communication, criminal justice, language, music, recreation, and sports management [9]. Due to its significance, mathematics has become one of the central issues in the framework of 21st-century education development [10]. This is because mastery of technology, science, and other disciplines cannot be separated from the role of mathematics. Difficulties in understanding mathematics, therefore, have direct implications for challenges in learning various fields, especially science (Castro et al., 2022).

Discussing the role of mathematics inevitably involves addressing the application of mathematical concepts beyond the boundaries of mathematics itself. The issue of applying mathematical concepts and skills is not new. According to the National Council of Teachers of Mathematics [12] in the United States, the ability to apply mathematical concepts has long been recognized as one of the essential skills to be developed in mathematics learning. This skill is commonly referred to as mathematical connection [12]. Mathematical connections enable individuals to use their knowledge of mathematical concepts or skills to understand other concepts. Connections among concepts within the domain of mathematics are referred to as Intra-Mathematical Connections (IMC), while connections between mathematics and concepts outside its domain are known as Extra-Mathematical Connections (EMC) [13], [14]. Mathematical connection is not only important but also serves as an indicator of mathematical proficiency [15]. In other words, a person who cannot connect mathematical concepts to other

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fields cannot yet be considered to have fully mastered those concepts.

With the continuous changes occurring across various dimensions of life (particularly in science and information technology) strong adaptability has become increasingly essential. Students in schools must be prepared to face emerging challenges and the dynamic situations that come with them. This means that, although the ability to make mathematical connections is not a new concept, it remains relevant and should continuously be developed among students to help them adapt to the changing times. In this context, we refer specifically to *Extra-Mathematical Connections* (EMC). In this article, we aim to provide empirical evidence on the relationship between the presence of mathematical concepts and the level of difficulty students experience in solving problems on Indonesia's Senior High School National Examination (UN).

Among the various fields of science studied in senior high schools (SMA) in Indonesia, physics is the subject that most extensively applies mathematics [16], [17]. As a result, mathematical ability becomes crucial since it serves as the fundamental basis for learning physics. Findings reported by several researchers have provided ample evidence that poor mastery of mathematics leads to an inability to solve problems in learning physics [18], [19], [20]

Other fields of science, such as chemistry, which also apply mathematics, remain under debate as to whether mathematical ability is a primary foundation for mastering chemistry or not. Indeed, several studies have revealed the role of various mathematical concepts in chemistry [21], [22], [23]. The presence of mathematical concepts makes the problem-solving process in chemistry more complex [21]. In other words, mathematics contributes to increasing the level of difficulty in solving chemistry problems or exercises. The more complex the mathematical concepts applied, the more difficult it becomes to solve problems in chemistry. Moreover, [NO_PRINTED_FORM] [21] emphasized that not only understanding but also fluency in mathematics is required to master chemistry [21]. This means that if one has not yet mastered the mathematical concepts used in chemistry, the complexity and difficulty of learning chemistry will increase significantly.

Unfortunately, the results of these studies generally focus on chemical concepts taught at the university level. In addition, most of these research findings cannot be generalized to a broader scope because the data used were collected from limited communities. On the other hand, studies that provide empirical evidence regarding the relationship between mathematical ability and the ability to solve various chemistry problems at the secondary education level are still rarely found. Similarly, research using large sample sizes is still scarce, leaving the debate about the role or influence of mathematics on the level of difficulty in solving chemistry problems unresolved.

In this article, we do not discuss the correlation (cause-and-effect relationship) between students' mathematical ability and their performance in solving chemistry problems in the Indonesian national examination (UN) for senior high school. Instead, we examine the relationship between the presence of mathematical concepts in chemistry and the ability to solve chemistry problems based on the difficulty level of the UN chemistry items. Within the framework of Classical Test Theory (CTT), item difficulty reflects the proportion of students who answer an item correctly (Fauzie et al., 2021).The easier an item, the greater the number of students who can answer it correctly [24].

In this study, mathematical concepts appearing in UN chemistry items were identified and linked to the corresponding item difficulty levels. To obtain information about the difficulty level of UN chemistry items, we used data from the national examination reports for senior high schools regularly published by the Research and Development Agency, Ministry of Education and Culture of the Republic of Indonesia (Balitbang, Kemdikbud RI). By utilizing these national examination data, it is expected that the findings of this study can be generalized and serve as a reference for the development of chemistry curricula in Indonesia in particular, as well as in other countries with secondary education standards similar to those of Indonesia.

In this context, this study does not focus on the correlation between students' mathematical ability and their performance in chemistry, but rather on the presence of mathematical concepts in chemistry problems and how these influence students' difficulty levels in solving them. Using longitudinal national examination data, this study aims to provide empirical evidence on the relationship between the application of mathematics and students' difficulties in solving chemistry problems in Indonesian high schools.

The research contribution is to offer empirical insights into how mathematical applications influence students' cognitive challenges in chemistry problem solving, by combining large-scale quantitative data with qualitative perspectives from teachers and experts. This contribution strengthens the understanding of interdisciplinary connections between mathematics and chemistry and provides evidence-based recommendations for improving science learning in secondary education.

1.1 Research objectives

Ideally, students who have mastered both mathematics and chemistry should be able to solve chemistry problems effectively. However, when difficulties occur, it is unclear whether they stem from complex chemical concepts or the use of mathematics. Therefore, this study aims (1) to examine the influence of mathematical application on students' difficulty in solving chemistry problems, and (2) to identify strategies used by teachers and students to overcome these difficulties.

2 Method

2.1 Research design

This descriptive-exploratory study used both quantitative and qualitative approaches. Quantitative data were drawn from five years of Indonesian National Examination (UN) results for senior high schools (2013–2017), covering about 1.8 million students from 34 provinces. Qualitative data were obtained through FGDs and interviews with three chemistry teachers, one chemistry education expert, and five students. The FGDs identified mathematical concepts in UN chemistry items, while interviews explored the causes of students' difficulties and strategies used or needed by teachers to address them.

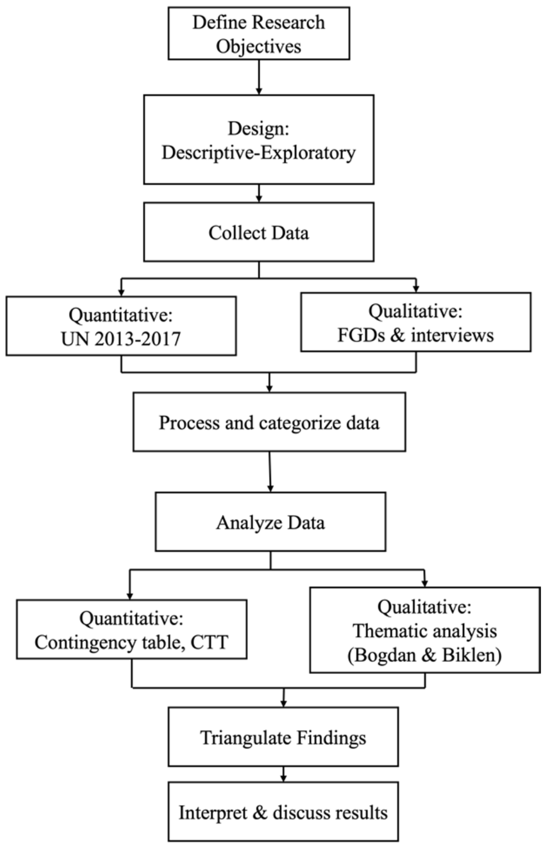


Fig. 1. Research methodology flowchart combining quantitative and qualitative approaches.

2.2 Participants

This study involved three experienced high school chemistry teachers (10–18 years), one chemistry education expert from a state university, and five 12th-grade students in Yogyakarta.

2.3 Data analysis

The effect of mathematical application on chemistry item difficulty was examined using contingency table analysis based on mapped UN chemistry indicators and their mathematical concepts. Item difficulty was determined using the Classical Test Theory (CTT) approach. Qualitative data from interviews and FGDs were analyzed using the Bogdan and Biklen [25] model to identify causes of difficulties and strategies to address them.

3 Findings

This section presents the results from both quantitative and qualitative data analyses. First, the quantitative findings from the 2013–2017 UN chemistry exam data are presented, followed by insights from interviews with teachers and a chemistry education expert. The qualitative results are organized to complement and support the initial quantitative analysis.

3.1 The effect of mathematical application on the difficulty of solving chemistry problems

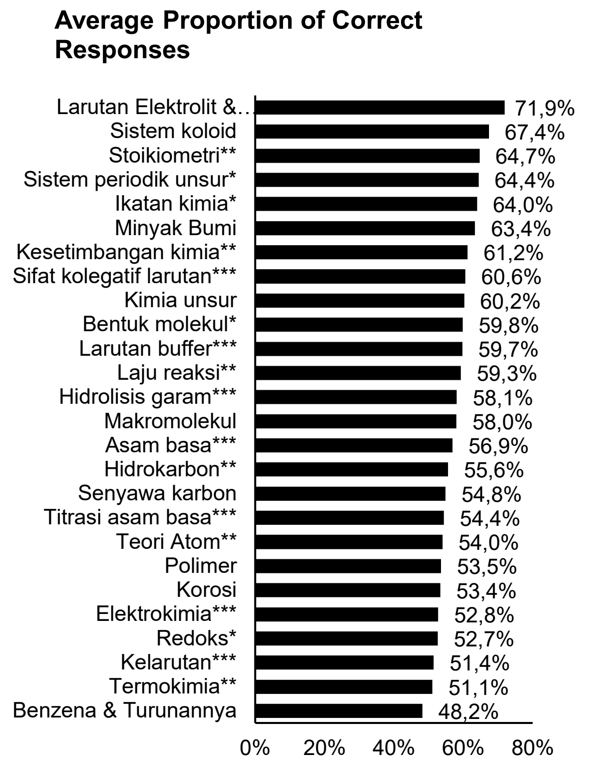
Quantitative analysis using contingency tables (Table 1) showed significance values greater than $\alpha = 0.05$ for the 2013–2017 UN chemistry exams. This indicates that there is no correlation between the application of mathematics and the difficulty level of the exam items. In other words, the presence or absence of mathematical concepts in the 2013–2017 UN chemistry items did not affect students' ability to solve these problems.

Table 1. The effect of mathematical application on the difficulty level of chemistry exam items.

Year	Chi-Square	df	Coef. Contingency	Sig.
2013	0.925	1	0.15	0.336*
2014	1.005	2	0.161	0.605*
2015	1.213	2	0.178	0.545*
2016	0.269	2	0.09	0.874*
2017	0.946	2	0.152	0.623*

**There is no correlation between the application of mathematics and the difficulty level of UN chemistry exam items.*

When examined based on the indicators of the 2013–2017 UN chemistry items, it is evident that the level of mathematics required to solve the problems did not affect students' ability to answer correctly. This finding emerged from mapping the UN chemistry indicators according to the mathematical concepts applied. Four categories of items were identified based on the mathematical concepts used: (1) no mathematics applied, (2) basic arithmetic operations, (3) algebra concepts, and (4) algebra and logarithm concepts (see Figure 1). Category four was considered the most mathematically complex. The data in Figure 1 show that the proportion of students answering correctly on items involving mathematics varied, but it did not depend on the complexity of the mathematical concepts. In other words, items in category four were not necessarily the most difficult. The most challenging items were often in category one. Some categories four items, such as stoichiometry, colligative properties, buffer solutions, and salt hydrolysis, were correctly solved by the majority of students. This indicates that the difficulty of UN chemistry items is primarily due to the complexity of the chemistry concepts themselves, rather than the mathematical application. Thus, students' difficulties largely depend on their mastery of chemistry concepts.



Notes:
* only applies basic aritmetic operations
** applies algebra concepts
*** applies algebra and logarithm concepts
Data Source: Balitbang, Ministry of Education and Culture, Republic of Indonesia [26], [27], [28], [29], [30]

Fig. 2. Average proportion of correct responses.

The results of the UN data analysis are also supported by qualitative data from interviews with teachers and the expert. The data reduction presented in Table 2 highlights three themes related to difficulties in solving chemistry problems. According to the chemistry education expert and the teachers, mathematical proficiency does influence students' performance in solving chemistry problems. However, the required mathematical skills are not highly complex formal mathematics.

The teachers emphasized that the mathematical concepts used in chemistry problems do not significantly affect students' difficulty in solving them. This is because the mathematics involved is generally simple and does not require advanced mathematical skills.

> "The computations in chemistry problems do not involve complicated numbers, so they are easy to calculate. Even when problems involve more complex mathematics, such as logarithms, the questions are designed so that the logarithm values are easy to work with." [Teacher_1].
>
> "The mathematical skills required are only basic operations such as multiplication, division, subtraction, ratios, logarithms, and geometric calculations." [Teacher 2].
>
> "The mathematics needed for learning high school chemistry is still simple, like addition, subtraction, multiplication, division, and simple square roots. Chemistry learning involves memorization, understanding, and calculations. While calculation ability affects the speed in solving some problems, understanding the various basic chemistry concepts is the key." [Expert].

Table 2. Causes difficulties in solving chemical problems.

Respondents (Teachers, Expert, Students)	Theme	Conclusion
• Students cannot identify what to calculate, which formula to use, or whether unit conversions are needed • Confused in selecting the correct formula to apply • Too many formulates to use	Difficulty applying chemistry concepts and formulas	Students' difficulties arise from not mastering the concepts, being unable to connect them, and failing to apply chemistry concepts correctly.
• Students struggle because they do not understand chemistry concepts • Inability to translate concepts into applications • Students' ability to link chemistry concepts with mathematical logic is low • Relationships between multiple chemistry concepts are not yet understood	Difficulty understanding chemistry concepts and their interconnections	
• Much of the chemistry material is abstract • Some material cannot be visualized by students • Difficult to memorize many abstract concepts	Difficulty understanding abstract chemistry material	

Although many high school chemistry topics involve mathematics—from basic arithmetic and algebra to logarithms—teachers and the expert agreed that these concepts do not substantially impact the difficulty of learning chemistry or solving UN chemistry problems. The following are selected comments from teachers and the expert regarding the mathematical concepts tested in the UN chemistry exams.

Stoichiometry

Stoichiometry involves other underlying chemistry concepts that students must master first, such as compound nomenclature, chemical formulas, chemical reactions, the mole concept, and other formulas used in chemical calculations. Therefore, to understand stoichiometry, students need to grasp all related topics beforehand. [Teacher 3].

Students' mathematical skills for performing calculations quickly and accurately are often insufficient, so they usually rely on calculation tools such as calculators to complete the computations. [Teacher 3].

Chemical Equilibrium

"This topic involves many mathematical calculations, such as determining K_c and K_p, which include division and fractions. However, the difficult UN questions are conceptual rather than computational. Students struggle due to a lack of understanding of dynamic equilibrium and the factors affecting equilibrium shifts. For example, in heterogeneous equilibrium, students often do not know which reactants to consider in terms of volume or stoichiometric coefficients." [Expert].

Atomic Structure

"The concepts of atomic theory are largely abstract, leading to many student misconceptions, especially regarding electron configurations in quantum mechanical atomic theory. While quantum mechanical atomic theory includes wave equations involving integrals, this is not taught at the high school level—students are only introduced to the final form of the Schrödinger equation." [Teacher_3].

Thermochemistry

"This topic requires careful calculation. For example, calculating ΔH using a calorimeter, ΔH^0f data, bond energies, and Hess's law must be done accurately. However, to master these calculations, students must first have a solid understanding of balanced chemical equations and chemical bonding concepts." [Teacher 1].

Analysis of the difficulty level of UN chemistry items from 2013 to 2017 shows an increasing trend in difficulty. In other words, the proportion of students correctly answering items has steadily decreased. Table 3 presents topics that most students struggled with, where no more than 55% of participants answered correctly. Considering the number of difficult items, there is a clear tendency for the number of challenging questions to rise from 2013 to 2017. Given this trend, corrective measures are necessary to prevent similar issues in future examinations.

Table 3. Chemistry national examination topics (2013–2017) categorized as difficult.

2013	2014	2015	2016	2017
Benzena & Its Derivatives [54.22] Polymer [54.50]	Buffer Solution [32.82] Corrotion [34.66] Acids and Bases [38.51] Hydrocarbon [40.05] Solubility [40.55] Thermochemistry [41.86] Electrochemistry [42.37] Benzene & Its Derivatives [43.95] Polymer [44.94] Molecular Shape [50.63]	Carbon Compounds [40.21] Benzene & Its Derivatives [40.83] Periodic System of Elements [41.18] Thermochemistry [44.82] Redox [46.4] Electrochemistry [47.55] Macromolecules [49.46] Acid-Base Titration [53.81] Chemical Elements [54.84]	Reaction Rate [37.12] Electrochemistry [41.99] Thermochemistry [43.13] Chemical Elements [43.89] Benzene & Its Derivatives [43.93] Carbon Compounds [44.05] Stoichiometry [45.08] Chemical Equilibrium [45.96] Corrosion [45.99] Solubility [46.66] Colligative Properties of Solutions [49.18] Acid-Base Titration [49.7] Molecular Shape [53.05] Macromolekuls [53.31] Buffer Solution [54.65]	Soluility [41.63] Carbon Compounds [41.74] Salt Hydrolysis [41.99] Colligative Properties of Solutions [44.09] Chemical Bonding [44.44] Macromolecules [46.26] Corrosion [46.4] Colloid System [46.42] Buffer Solution [47.02] Electrochemistry [47.19] Thermochemistry [48.02] Chemical Equilibrium [48.24] Acid and Bases [49.13] Hydrocarbon [51.22] Electrolyte and Nonelectrolyte [52.34] Molecular Shape [53.44] Stoichometry [53.77] Acid-Base Titration[53.9] Atomic Theory [54.02] Benzene & Its Derivatives [54.98]

Proportion of Correct Responses %;
The proportion of students answering correctly for the topics listed in the table did not exceed 55%
Data Source: Balitbang, Ministry of Education and Culture, Republic of Indonesia [26], [27], [28], [29], [30].

Teachers' Strategies to Overcome Students' Difficulties in Solving Chemistry Problems

From the interviews, four themes emerged regarding the strategies teachers use to help students overcome difficulties in solving UN chemistry problems. Three of these themes focus on improving students' understanding of chemistry concepts, while the fourth emphasizes training students to solve problems, including the mathematical calculations required in chemistry items.

Teachers reported using various media and teaching aids, conducting laboratory practicums, and assigning tasks to enhance students' comprehension of abstract chemistry concepts (see Table 4). Problem-solving exercises are employed to train students to follow mathematical algorithms and apply formulas correctly when solving questions.

These strategies reflect teachers' efforts to anticipate the challenges students may face in the UN. However, four out of five teachers admitted that they have never comprehensively analyzed or used UN results as a tool to evaluate teaching practices. In other words, the UN results have not yet been utilized as a diagnostic tool to identify the difficulties most frequently encountered by students.

Table 4. Teachers' strategies to overcome students' difficulties.

Teacher Responses	Theme	Conclusion
• Train students' understanding through laboratory practicums • Conduct practicums so students can observe directly and remember	Training students through practical activities	Teachers conduct laboratory practicums, use various media, and assign tasks to help students understand chemistry concepts. Exercises are also provided to strengthen students' problem-solving skills, especially for calculations.
• Use molimood or clay to explain molecular shapes • Use 2D media or 3D animations for abstract topics • Provide real-life examples • Create concept maps • Reinforce understanding through analogies • Use simplified methods to grasp chemistry concepts	Explaining abstract concepts using visual media and teaching aids	
• Guide and provide tips for mathematical calculations • Practice writing ionization reactions • Practice solving problems • Discussions and problem-solving exercises • Step-by-step explanations from calculating Mr, moles, reaction equations, basic laws, mole concept, to chemical calculations	Training and guiding students in problem-solving	
• Asign students to make papers or PowerPoint presentations • Assign tasks that enable understanding without memorization • Group presentations	Assigning tasks for students to study and present chemistry concepts	

The strategies implemented by most teachers confirm the analysis regarding the effect of mathematical application on the difficulty of UN chemistry questions. A lack of understanding of chemistry concepts is viewed as a more fundamental issue than students' mathematical abilities. Therefore, nearly all teacher respondents prioritized enhancing students' understanding of chemistry concepts as the primary approach to overcoming their difficulties.

4 Discussions

Many factors can influence students' success in learning chemistry, just as several factors contribute to their failure. This study reveals that the presence of mathematical concepts within chemistry is not the cause of students' difficulties in solving UN chemistry problems. The findings provide evidence regarding the causal relationship between the application of mathematics and the difficulty students experience in solving chemistry problems, particularly at the secondary education level.

Based on qualitative data, three themes emerged regarding students' difficulties in solving chemistry problems. First, students struggle to understand chemistry concepts due to their abstract nature. Second, students have difficulty understanding the connections between one chemistry concept and another, or between chemistry concepts and concepts from other domains. These two difficulties prevent students from correctly interpreting the context of chemistry problems. Without understanding the problem context, students are hindered in finding solutions [31], [32]. Third, students struggle to apply concepts, mainly because they cannot identify which formulas, equations, or concepts to use, including unit conversions and other procedures. This difficulty is further compounded by the large number of formulas in chemistry. Neither teachers nor students reported major challenges in performing calculations or applying mathematical concepts. The primary source of difficulty lies in failing to select the appropriate formula, equation, or concept.

The difference in the characteristics of chemistry concepts studied at the secondary and tertiary levels appears to be one explanation for our findings. [NO_PRINTED_FORM] [23] examined the mathematical difficulties faced by university students in the context of chemistry. Their study found that students' struggles were not due to difficulties in transferring mathematical knowledge but rather because of their low mathematical proficiency [23].

In contrast, our findings indicate that mathematics proficiency is not a barrier to solving UN chemistry problems at the high school level in Indonesia. This is because the mathematical concepts applied in high school chemistry are relatively simple. As revealed in FGDs and interviews with teachers and experts, strengthening students' conceptual understanding is the primary focus in high school chemistry instruction. Consequently, the mathematical concepts used are simplified to avoid adding cognitive load [33].

Arithmetic operations in high school chemistry are kept as simple as possible to facilitate easier calculations.

At the university level, however, chemistry concepts increasingly involve more complex mathematical applications, such as natural logarithms, derivatives, and even integrals [34]. Therefore, low mathematical proficiency leads to difficulties in solving chemistry problems in higher education. Similarly, [NO_PRINTED_FORM] [35] found that first-year university students' difficulties in chemistry were due to low numerical skills.

Our study contrasts with previous research claiming that high school students' difficulties in learning and solving chemistry problems stem from low mathematical ability [36], [37] even concluded that "students with very low mathematical ability should not be allowed to enroll for chemistry". Evidence from our study shows that the most difficult high school chemistry questions were those not involving mathematics (e.g., benzene and its derivatives), whereas topics with higher mathematical complexity (e.g., stoichiometry, colligative properties, buffer solutions, and salt hydrolysis) were correctly solved by the majority of students (over 60%).

Mathematical ability, often considered a key factor causing students' difficulties in solving chemistry problems, is not supported by the findings of this study [36]. In fact, a study conducted by university students enrolled in a physical chemistry course found that math skills are not even the best predictor of performance in physical chemistry. The math skills in focus in their study included calculus, algebra, and word problems. Their findings emphasize that even in university-level physical chemistry, which applies mathematics at a more complex level, mathematics is not the determining factor for success in learning it. The abstract nature of chemistry content [38] is one of the main causes of students' difficulties in understanding it. Although success in some university-level chemistry topics that involve mathematical concepts is strongly influenced by math ability [21], [39], at the high school level, the situation shows slight differences. It is also important to emphasize that this study does not conclude that students with strong mathematical abilities do not influence their success in chemistry. This study only discusses the effect of the presence of mathematics on students' difficulties. In other words, the findings cannot be used as an argument that good mathematical knowledge is unnecessary in high school chemistry.

If we look at the strategies mentioned by teachers to anticipate students' difficulties in solving UN chemistry problems, there is a tendency among teachers to strengthen students' understanding of chemistry concepts. Teachers mentioned at least three concept-strengthening strategies to overcome students' difficulties in the UN. First, maximizing the function of the laboratory to conduct practical experiments. Second, using various media to explain abstract concepts. Third, assigning tasks or involving students in learning various chemistry concepts.

When compared to the study conducted by [40], the teacher responses in this study show similarities. In his study, [NO_PRINTED_FORM] [40] also mentioned that strategies employed by teachers to overcome difficulties in chemistry included using the laboratory more efficiently and making abstract concepts more concrete. In addition, [NO_PRINTED_FORM] [40] found that improvements were also needed in assessment procedures, improving library/resources, and less crowded classes. They also emphasized the need to increase student involvement in learning activities and to actively complete homework and pre-class work. However, teachers did not mention strategies related to lesson planning models, including assessment models necessary to anticipate students' difficulties. In fact, lesson planning and assessment design are crucial in determining the outcomes of the learning process [41], [42].

Thus, planning the learning model and assessment model is crucial to help students understand various chemistry concepts. Difficulties in understanding context can be addressed by familiarizing students with learning chemistry through various familiar contexts. Project-Based Learning (PjBL) can be an alternative approach for teachers to achieve this goal [43], [44]. Students can also be supported by using various media to visualize abstract concepts. In addition, laboratory activities cannot be separated from efforts to enhance students' understanding of chemistry concepts, particularly regarding the processes or products resulting from chemical reactions. Ideally, in the future, students will not only focus on solving problems in the classroom but will also be trained to explore concepts and build connections between different concepts.

When compared with previous studies, these findings present a different perspective on the role of mathematics in chemistry learning. Several studies [24], [35], [36], [37], [38] found that low mathematical proficiency contributes to students' difficulties in understanding and solving chemistry problems, especially at the university level where calculus and algebraic reasoning are more dominant. In contrast, this study demonstrates that for high school students, the presence of mathematics in chemistry problems does not significantly increase their difficulty level. This difference is mainly due to the simpler mathematical demands of secondary chemistry and the greater influence of conceptual understanding on problem-solving success.

The findings of this study align with the view of Gulacar et al. [39] and Banerjee & Gautam [40], who emphasize that conceptual mastery and representational understanding are stronger predictors of chemistry performance than mathematical skills alone. These results imply that strengthening students' conceptual comprehension through contextual and practical learning may be more effective than focusing only on mathematical drills.

The strength of this research lies in the use of large-scale national examination data combined with qualitative validation from teachers and experts, which provides a broad and reliable picture of students' learning difficulties. However, the study is limited by its dependence on secondary data and a relatively small number of interview participants. Future research is suggested to conduct classroom-based interventions or longitudinal studies to further confirm the relationship between conceptual understanding and mathematics in chemistry learning.

5 Conclusions and recomendation

Based on the results of the quantitative and qualitative data analyses described above, it can be concluded that the application of mathematics in chemistry questions does not affect the level of difficulty students experience in solving chemistry problems. The difficulties are predominantly caused by the complexity of the chemistry concepts themselves, including challenges in understanding and applying concepts, as well as connecting different concepts within chemistry. Strategies employed by teachers to address these difficulties include maximizing the use of laboratories, utilizing various media and teaching aids to explain abstract concepts, assigning tasks, and providing exercises to practice solving chemistry problems.

Although this study analyzed large-scale national examination data representing students from across Indonesia, it is limited by its reliance on secondary data and a relatively small number of interview participants. These limitations may restrict the generalization of the qualitative findings to diverse classroom contexts. Future studies are therefore recommended to include classroom-based investigations, larger and more varied samples of teachers and students, and comparisons across different science subjects. Such research could further explore how strengthening conceptual and contextual learning helps reduce students' difficulties and enhances the integration of mathematics and science learning.

Overall, the findings of this study can serve as a valuable reference for policymakers, chemistry education experts, practitioners, and high school chemistry teachers across Indonesia in planning and implementing effective chemistry learning programs.

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