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The Relationship Between Prior Knowledge and Students' Chemical Literacy

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Abstract: Chemical literacy is a key component of scientific literacy, enabling individuals to understand, evaluate, and apply chemical concepts in real-life situations. This study investigates the relationship between students' prior knowledge and their chemical literacy on acid-base topics in senior high school. The study employed a quantitative descriptive method with a correlational approach, involving 99 eleventh-grade students from three accredited private schools in Padang City, Indonesia. Two validated instruments were used to collect data: the Structured Essay Diagnostic Test of Chemistry (SEDToC) to assess prior knowledge, and a discourse-based chemical literacy test. Data analysis included descriptive statistics and Spearman's Rank correlation. Results revealed a very weak and statistically insignificant positive correlation between prior knowledge and chemical literacy ($r_s = 0.1454$; $p > 0.05$), with a coefficient of determination (r^2) of 2.1%. Stoichiometry emerged as the subtopic with the highest level of understanding (41.68%), while chemical bonding was the lowest (3.05%). Although most students demonstrated procedural understanding, many struggled with contextual and discourse-based questions that required higher-order thinking. A high rate of misconceptions (36.59%) was also identified, which negatively affected students' ability to reason and interpret chemical phenomena accurately. This study highlights that conceptual understanding alone is insufficient to support chemical literacy. The novelty of this research lies in its focus on chemical literacy as a multidimensional construct, beyond mere content mastery. The findings suggest that instructional strategies should not only strengthen prior knowledge but also integrate real-world contexts and promote critical thinking. Future research is recommended to explore other contributing factors such as motivation, metacognitive awareness, and teaching approaches that could better foster students' chemical literacy. To support this, educators should design learning strategies that go beyond reinforcing prior knowledge and emphasise contextual, inquiry-based, and reflective approaches to develop students' comprehensive chemical literacy.

Keywords: Chemistry Literacy; Misconception; Prior Knowledge; Acid-Base; Science Education.

Introduction

Scientific literacy is an essential 21st-century competency, enabling individuals to make informed decisions through the comprehension and application of scientific knowledge [1], [2]. In education, scientific literacy includes understanding scientific concepts, critical thinking, information evaluation, and knowledge integration in social and environmental contexts [3]. A vital component of this literacy is chemical literacy, the capacity to grasp chemical principles, engage in scientific reasoning, and apply chemical knowledge to real-world and global challenges.

Chemical literacy extends beyond factual comprehension, demanding the ability to contextualize chemical concepts in social, environmental, and technological domains [4], [5]. The Merdeka Curriculum explicitly identifies this skill as foundational for fostering students' critical, creative, and adaptive thinking [6]. Nevertheless, Indonesian students' performance in scientific literacy remains subpar. The PISA 2022 results placed Indonesia 70th out of 81 countries, with a scientific literacy score of 359, the lowest since Indonesia's participation [7].

One significant factor influencing low chemical literacy is inadequate prior knowledge. Prior knowledge serves as a cognitive foundation for assimilating new information [8], [9]. Students with robust prior knowledge can more easily integrate new material with existing cognitive structures, thereby achieving meaningful learning. In contrast, conceptual misunderstandings or gaps in foundational knowledge hinder learning progression and scientific literacy.

The acid-base topic is central to high school chemistry curricula, given its relevance to both everyday life and industrial applications [10], [11]. However, it remains a challenging subject due to its abstract nature and the complexity of conceptual models involved [12]. Common student difficulties include differentiating between Arrhenius, Brønsted-Lowry, and Lewis acid-base definitions, performing pH calculations, and understanding acid-base strength and its applications [13].

A preliminary survey conducted in six accredited private high schools in Padang showed that only 36% of students demonstrated adequate understanding of acid-base concepts. Meanwhile, 28% exhibited misconceptions, and 40% lacked comprehension entirely. Students also reported difficulty with pH calculations and interpreting chemical texts, highlighting deficiencies in their chemical literacy. While high classroom test scores were observed, these often reflected low-order cognitive skills such as rote memorization. Previous studies suggest a correlation

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between prior knowledge and chemistry achievement [14]. and critical thinking abilities [13]. However, there is a research gap regarding the specific relationship between prior knowledge and chemical literacy, especially on acid-base topics. Most existing literature explores general academic performance rather than the multifaceted construct of chemical literacy.

Recent studies have attempted to investigate how foundational conceptual understanding impacts students' broader literacy skills. For instance, Irawati [15] demonstrated that students' understanding of acid-base concepts significantly influenced their ability to grasp the topic of salt hydrolysis, with a coefficient of determination of 51.5%. This indicates a strong academic link between prior knowledge and subsequent concept mastery, although it remains largely focused on test performance. Similarly, Zandroto and Sinaga [16] analyzed students' chemical literacy on hydrocarbon topics through a contextual approach. Although the study assessed indicators such as identifying scientific issues and applying evidence-based reasoning, it did not explicitly measure prior knowledge as a variable. Instead, students' success was inferred from their performance on literacy tasks, again emphasising academic achievement rather than direct literacy development.

In contrast, this study explicitly examines the relationship between prior knowledge and chemical literacy using discourse-based instruments that capture students' ability to interpret, evaluate, and apply chemical concepts in real-world contexts. By moving beyond test scores and academic metrics, this research aims to offer a more comprehensive understanding of how prerequisite knowledge can serve as a foundation for multidimensional chemical literacy.

This study seeks to address this gap by examining the relationship between prior knowledge and students' chemical literacy concerning acid-base topics, and by determining which specific subtopics of prior knowledge have the most substantial impact. The findings are intended to inform theoretical advancements in chemistry education and guide instructional design to better utilize students' prior knowledge.

Research Methods

This study employed a quantitative correlational research design to assess the relationship between students' prior knowledge and their chemical literacy in acid-base topics. The correlational method was selected because it enables the analysis of the degree and direction of the association between two variables without manipulation, which is appropriate for educational settings where experimental control is limited [17].

Two validated instruments were used in this study: the Structured Essay Diagnostic Test of Chemistry (SEDToC) to measure prior knowledge and the Discourse-Based Chemical Literacy Test developed and validated by Wahyuni and Yusmaita [18] to assess students' chemical literacy. The SEDToC instrument was selected for its structured and diagnostic format, which allows for deep insight into students' prerequisite understanding across several subtopics (atomic structure, bonding, reactions, stoichiometry, and equilibrium). The literacy test, on the other hand, emphasizes students' ability to interpret and reason through contextualized chemical scenarios, aligning with multidimensional views of chemical literacy.

Content validity of the SEDToC was tested using the Item -Content Validity Index (I-CVI), achieving a mean I-CVI score of 0.98, indicating excellent content validity. A CVI value ≥ 0.80 is considered acceptable Polit & Beck [16]. Reliability was tested using Cronbach's Alpha, and the SEDToC instrument yielded a coefficient r11 = 0.76, indicating high reliability. The discourse-based chemical literacy test also showed content validity, with an average I-CVI score of 0.804, confirming that both instruments are valid and reliable for assessing prior knowledge and chemical literacy.

The population comprised eleventh-grade science students (Phase F) from six A-accredited private high schools in Padang City: Adabiah 1, Adabiah 2, Kartika 1-5, PGRI 1, Eka Sakti, and Pertiwi 1. Using simple random sampling, three schools, Adabiah 1, Adabiah 2, and Kartika 1-5, were selected. These schools were chosen based on their accreditation status and strong academic profiles, which reflect national education standards [19]. Private schools were selected for their typically smaller teacher-student ratios, flexible curricula, and institutional commitment to educational quality. Despite these strengths, research on private schools remains limited; thus, this study offers valuable insights into improving instructional effectiveness in such institutions [20].

The sample consisted of 99 students selected using simple random sampling, ensuring each member of the population had an equal chance of selection. This method improves generalizability and reduces sampling bias. Students completed both the SEDToC and the Chemical Literacy Test in a 90-minute session. The total time for completing both instruments was 5 lesson periods (JP), with each JP lasting 45 minutes. Each SEDToC item was scored using a binary rubric (1 = correct; 0 = incorrect), followed by conceptual analysis using Marek's [21] framework: "Did Not Understand," "Misconception," and "Understood."

Responses from the literacy test were assessed using the following rubric based on literacy levels:

Table 1. Chemical Literacy Categories

Score	Level	Description
0	Scientific Illiteracy	Cannot answer or gives an incorrect answer
5	Nominal Scientific Literacy	Answers correctly but with misconceptions
10	Functional Scientific Literacy	Correct answer, but limited understanding
15	Conceptual Scientific Literacy	Correct answer and able to relate concepts
20	Multidimensional Scientific Literacy	Correct, broader explanation with advanced scientific reasoning

Additionally, students' responses on the SEDToC were categorized based on their conceptual understanding using the following criteria in Table 2. In addition, structured interviews were conducted with 30% of the sample to support the quantitative findings and explain observed trends.

Table 2. Conceptual Understanding [21]

Category	Level of Understanding	Assessment Criteria
Not Understanding	No Response	1. No answer/empty2. Answers "I don't know"3. Answers "I don't understand"
	Not Understanding	1. Copies the question2. Answer unrelated to question3. Unclear response
Misconception	Misconception	1. Answer is incorrect2. Includes inaccurate information
	Partial Understanding with Misconception	1. Contains some correct ideas but also misconceptions2. Partially accurate
Understanding	Partial Understanding without Misconception	1. Correct answer without misconceptions2. Basic but accurate understanding
	Complete Understanding	1. Logical, accurate, complete, and demonstrates full understanding

Data analysis was conducted using SPSS version 26 and involved descriptive statistics, assumption testing, and hypothesis testing. Descriptive analysis provided an overview of students' prior knowledge and chemical literacy levels. Given the ordinal nature of the data and non-normality based on the Kolmogorov-Smirnov test, the non-parametric Spearman Rank correlation was used. The correlation strength was interpreted following Sugiyono [17], with a significance level set at $\alpha = 0.05$. The coefficient of determination (r^2) was also calculated to evaluate the proportion of variance in chemical literacy explained by prior knowledge.

Results and Discussion

This study involved 99 students from three A-accredited private high schools in Padang City. The purpose of the study was to analyze the relationship between students' prior knowledge and their chemical literacy on acid-base concepts. Data were collected using two standardized instruments: the Structured Essay Diagnostic Test of Chemistry (SEDToC) to measure prior knowledge, and a chemical literacy test to assess students' literacy ability. Data analysis employed both descriptive and inferential statistics, using the non-parametric Spearman test due to non-normal data distribution according to the Kolmogorov-Smirnov test.

Distribution of Prior Knowledge Responses

Responses from a total of 2,574 SEDToC items were categorized into three levels: "Understood," "Misconception," and "Did Not Understand." The results are shown in Table 1.

Table 3. Distribution of Prior Knowledge Response Categories

Response Category	Frequency	Percentage (%)
Did Not Understand	57	2.21
Misconception	942	36.59
Understood	1576	61.22
Total	2574	100

The majority of students' responses were in the "Understood" category (61.22%). However, the high percentage of misconceptions (36.59%) indicates that over one-third of the students had incorrect conceptions about the fundamental chemical principles, pointing to shallow conceptual understanding.

Analysis of Understanding Based on Prerequisite Subtopics

Students' conceptual understanding within the "Understood" category was further analyzed according to five prerequisite subtopics: atomic structure, chemical bonding, chemical reactions, stoichiometry, and chemical equilibrium. The results are presented in Table 2.

Table 4. Distribution of Understanding in Prerequisite Subtopics

Subtopic	Percentage of Understanding (%)
Atomic Structure	15.74
Chemical Bonding	3.05
Chemical Reactions	21.45
Stoichiometry	41.68
Chemical Equilibrium	18.08
Total	100

The analysis of students' understanding across prerequisite subtopics reveals significant variation in conceptual grasp and the ability to apply knowledge to acid-base chemistry. In the domain of Atomic Structure, while students generally demonstrated a basic understanding of subatomic particles, they struggled to connect this knowledge to acid-base behavior. For instance, many were unable to explain how factors such as electronegativity or electron configurations influence acid strength or predict the identity of proton donors. Chemical Bonding emerged as the weakest area, where students often relied on memorization, simply categorizing compounds as ionic or covalent without understanding the implications of these classifications for molecular polarity or dissociation in aqueous solutions. A prevalent misconception was the assumption that all ionic compounds behave as bases.

In terms of Chemical Reactions, students showed adequate proficiency in balancing equations and recognizing the law of conservation of mass. However, their comprehension of acid-base reaction mechanisms, particularly the process of proton transfer and the rationale behind neutralization was limited. Stoichiometry was the highest performing subtopic, with 41.68% of responses categorized as demonstrating understanding. Students were capable of performing calculations involving moles, molarity, and volume, yet these skills were largely algorithmic. Very few students could extend these calculations to meaningful chemical interpretations, such as anticipating the resulting pH of a solution.

Chemical Equilibrium, a core concept in understanding weak acids, bases, and buffer systems, posed considerable difficulty. Students struggled to interpret shifts in equilibrium or apply Le Châtelier's principle in acid-base contexts. The concept of equilibrium constants (Ka and Kb) remained abstract for most, often reduced to rote memorization without a grasp of their relevance to system behavior. Taken together, the data indicate that students' understanding remained fragmented across subtopics. The ability to transfer knowledge from atomic-level concepts to macroscopic acid-base phenomena was notably limited, hindering their capacity to engage in integrated scientific reasoning.

Normality Test and Correlation Analysis

A normality test using the Kolmogorov-Smirnov method was conducted. The results are presented in Table 3.

Table 5. Kolmogorov-Smirnov Normality Test Results

Variable	K-Statistic	K-Critical	Distribution
Prior Knowledge	0.2170	0.1366	Non-normal
Chemical Literacy	0.1356	0.1366	Normal

Since one variable did not follow a normal distribution, the non-parametric Spearman Rank correlation test was employed. Results are displayed in Table 4.

Table 6. Spearman Rank Correlation Results

Variable Pair	N	r_s	p-value	Interpretation
Prior Knowledge-Chemical Literacy	99	0.1454	1.849	Very weak, not significant

The coefficient of determination (r^2) was 0.021, indicating that only 2.1% of the variance in chemical literacy could be explained by prior knowledge. The remaining 97.9% is likely influenced by other factors such as teaching strategies, motivation, critical thinking skills, and learning environments.

These results highlight that the relationship between prior knowledge and chemical literacy is neither linear nor straightforward. Although many students demonstrated procedural competence, particularly in algorithmic tasks such as stoichiometric calculations, their ability to solve context-based literacy problems was significantly limited. This suggests a weak transfer of knowledge from surface-level understanding to deeper, integrated scientific reasoning. For example, students often managed to calculate moles and concentrations correctly but struggled to interpret what these values meant in terms of pH changes, reaction direction, or chemical behavior in real-world scenarios. The strong performance in stoichiometry, while indicating proficiency in routine exercises, did not translate into meaningful comprehension or application when students were presented with complex, contextualized problems that required higher-order thinking skills.

Moreover, the low levels of understanding observed in subtopics such as chemical bonding and equilibrium underscore the presence of substantial conceptual barriers. Students frequently exhibited confusion regarding bond polarity, dissociation, and the implications of equilibrium shifts in acid-base reactions. This lack of conceptual clarity severely limited their ability to reason through mechanisms involving weak acids, bases, or buffer systems, an essential component of chemical literacy. Misconceptions were prevalent in over one-third of the student population, further complicating the issue. Commonly held incorrect beliefs, such as the idea that all acids are inherently corrosive or that a pH of 7 is universally neutral, impede logical reasoning and the accurate interpretation of chemical phenomena, especially in varied and dynamic contexts.

These findings also reinforce that while 61.22% of students were categorized as "understood," their actual level of chemical literacy remained low. This gap underscores the difference between procedural knowledge and conceptual understanding. It aligns with earlier studies indicating that algorithmic competence does not necessarily equate to deep conceptual grasp [22], [23]. Gabel [24] similarly observed that students often solve chemical calculations correctly without fully comprehending the underlying scientific principles, such as ionization or particle interactions in solutions. These results support Nakhleh's [25] distinction between algorithmic and conceptual understanding in chemistry. Therefore, it is essential that teachers go beyond emphasizing quantitative procedures, encouraging students to articulate the rationale behind formulas, the significance of calculations, and the relevance of concepts to real-life contexts.

To address these challenges, instruction should integrate the three levels of chemical representation macroscopic, submicroscopic, and symbolic as proposed by Johnstone [26]. Misconceptions often arise when students fail to connect these representations during learning and reasoning processes. Recent studies affirm the effectiveness of this multi-representational approach. For instance, [27] reported that explicitly linking these levels within buffer solution topics significantly improved students' conceptual understanding, yielding an N-gain of 0.62 (moderate category). Similarly, Rahmawati [28] found that interactive PhET simulations in chemical equilibrium topics reduced misconceptions and enhanced representational comprehension.

Practically, this approach can be implemented as follows:

a) Macroscopic: using visual demonstrations like color changes in pH indicators during acid-base reactions.
b) Submicroscopic: presenting animations or simulations that illustrate ionic interactions in solution.
c) Symbolic: writing complete ionic equations and explaining equilibrium constants.

These strategies can directly target misconceptions identified in this study, such as errors in identifying chemical bonds or writing equilibrium expressions. Emphasizing the connections among representations enriches conceptual understanding and promotes students' critical thinking skills [29], [30].

In conclusion, the study's findings underscore the urgent need for educators and curriculum developers to shift focus from traditional rote-based instruction to approaches that develop students' scientific reasoning and application skills. Cultivating robust chemical literacy involves equipping students with the ability to think critically, interpret complex data, and apply their knowledge to solve novel problems in real-world situations. Without such an emphasis, students may continue to perform well on procedural tasks while lacking the deeper understanding needed for meaningful scientific engagement and informed decision-making in their everyday lives.

Conclusion

The findings of this study indicate that although a majority of students (61.22%) demonstrated adequate prior knowledge in acid-base topics, their overall chemical literacy remained notably low. The Spearman rank correlation analysis revealed a very weak and statistically non-significant positive correlation ($r\rho = 0.1454$; $p > 0.05$), with a coefficient of determination (r^2) of only 2.1%. This suggests that prior knowledge contributes minimally to students' chemical literacy, and the remaining 97.9% is likely influenced by other variables, including instructional design, metacognitive ability, classroom discourse, student motivation, and the use of representational tools. Further analysis of prerequisite subtopics revealed inconsistent patterns of understanding. Students exhibited better performance in algorithmic subtopics such as stoichiometry, particularly in calculations involving moles and concentrations. However, these skills were largely procedural and did not translate into conceptual understanding, especially when interpreting pH changes or buffer systems. Conversely, subtopics such as atomic structure and chemical bonding showed the weakest comprehension, where students relied heavily on memorization and failed to relate microscopic structures to macroscopic acid-base behavior. Moreover, a high prevalence of misconceptions, such as assuming that all acids are corrosive or that pH 7 is always neutral, indicates a disconnect between factual knowledge and its application in diverse chemical contexts. These misconceptions impair students' ability to reason scientifically and limit their capacity to apply knowledge meaningfully in real-world scenarios. Therefore, chemical literacy must be seen not merely as the possession of fragmented scientific facts, but as an integrated ability that encompasses conceptual reasoning, critical thinking, and contextual application through the three levels of chemical representation: macroscopic, submicroscopic, and symbolic. These results underscore the urgent need for pedagogical approaches that go beyond rote memorization and promote deeper cognitive engagement. Teachers are encouraged to implement literacy-based strategies that emphasize the interconnectedness of chemical concepts, contextual learning, and tasks that develop higher-order thinking skills (HOTS).

Author's Contribution

Nur Indah Pebriani: conceptualization, data collection, data analysis, writing original draft. Faiza Qurrata Aini: supervision

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