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Identification of Student Misconceptions Using a Five-Tier Multiple-Choice Diagnostic Test on the Topic of Acids and Bases for Grade XI Students at SMA Negeri 10 Pekanbaru

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Abstract

The interconnected nature of chemical concepts makes foundational understanding essential, as conceptual errors can contribute to misconceptions about more advanced topics. This study aimed to identify the prevalence and sources of misconceptions across acid–base sub-concepts among Grade XI students at SMA Negeri 10 Pekanbaru. A quantitative descriptive design was employed, involving 163 students in the 2025/2026 academic year. Data were collected using a 20-item five-tier multiple-choice diagnostic test covering five sub-concepts, supplemented by structured interviews with 15 students. The overall misconception rate was 46.29%, classified as moderate. Misconceptions were most prevalent in the ionization equilibrium constants (Ka and Kb) sub-concept (48.77%), followed by pH (47.55%), acid–base theory (46.17%), acid–base indicators (45.55%), and acid–base strength (43.40%). Personal reasoning was the most frequently identified source of misconceptions (47.3%), followed by textbooks (16.8%), teachers (14.6%), peers (13.2%), and the internet (8.2%). These findings indicate that misconceptions occurred across all five sub-concepts, with personal reasoning identified as the dominant source. The study provides a profile of acid–base misconceptions that can inform diagnostic assessment and instructional planning. It highlights the need for teachers to identify students' conceptual difficulties and design targeted instructional strategies to strengthen understanding of acid–base chemistry.

Keywords: Chemistry Misconceptions; Five-Tier Diagnostic Test; Acid–Base Chemistry; Conceptual Understanding; Chemistry Education

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INTRODUCTION

Education is a process designed to facilitate learning and the attainment of competencies among students. Achieving these competencies depends not only on the delivery of material but also on the quality of the students' understanding of the concepts being studied (Awwalin & Nugroho, 2024). In chemistry education, conceptual understanding is particularly crucial because the various concepts are strongly interconnected and serve as prerequisites for subsequent learning. If a concept is misunderstood, that misconception can persist when students encounter other, more complex concepts. Mubarak & Yahdi, (2020) highlight the need to address misconceptions in chemistry education, as they can hinder the development of an understanding that aligns with scientific concepts.

Chemistry is a field characterized by its abstract nature and its reliance on macroscopic, submicroscopic, and symbolic representations (Rohmah & Raharjo, 2024). These characteristics often make it difficult for students to link observed phenomena with the particle models and chemical equations used to explain them. Nufus & Silfianah, (2023) explain that the complexity of scientific concepts can be a source of learning difficulties. In certain situations, students construct explanations based on their own experiences, intuition, or personal interpretations. When these explanations do not align with scientific conceptions, misconceptions arise. Damsi & Suyanto, (2023) define a misconception as an understanding that is inconsistent with accepted scientific concepts.

A misconception is not merely an error in answering a question. Students may provide incorrect answers for various reasons, a lack of understanding of the material, guessing, or holding a belief in a concept that is actually flawed (Putra et al., 2020). Distinguishing between these causes is vital for teachers, as subsequent instructional interventions must be tailored to the students' actual level of understanding. Sihaloho et al., (2021) demonstrate that unidentified misconceptions can impede the process of forming a correct scientific understanding. Furthermore, Utami et al., (2020) show that misconceptions left unaddressed can carry over into subsequent topics. Thus, identifying misconceptions is a crucial aspect of evaluating chemistry learning.

One topic requiring attention is acids and bases. This subject matter encompasses not only definitions of acids and bases based on various theories but also covers acid-base strength, ionization constants, ion concentrations, pH, and acid-base indicators. These sub-concepts are interconnected; consequently, an error regarding one concept can affect the

understanding of others. Siska & Ritonga, (2021) reported that the topic of acids and bases is challenging because it involves abstract concepts and inter-conceptual relationships. Furthermore, this material serves as a foundation for understanding advanced topics such as buffer solutions and salt hydrolysis.

Various studies indicate that misconceptions regarding acids and bases arise across several sub-concepts at varying levels. Rokhim et al., (2023) identified misconceptions when students determined acid strength based on inappropriate indicators. Laliyo et al. (2023) also detected misconceptions concerning acid-base theories using a two-tier instrument. Research by Yomaki et al., (2026), utilizing a four-tier instrument, revealed misconceptions regarding acid-base theories, acid-base strength, ionization constants, pH, and indicators. Fajar et al., (2023) similarly reported that misconceptions regarding acids and bases persist in several schools in Pekanbaru. These findings demonstrate that the issue of misconceptions is not limited to a single sub-concept and can vary depending on the learning context.

Differences in diagnostic instruments also influence the depth of information obtained. Two-tier instruments typically combine answer choices with reasons but do not adequately distinguish between students who hold misconceptions and those who simply lack an understanding of the concept. Azizah et al., (2022) highlighted the limitations of multi-tier instruments in differentiating levels of understanding when information regarding confidence is insufficient. The four-tier approach provides more detailed information regarding confidence but does not directly identify the source of the conception. Afifah et al., (2020) explain that the five-tier approach was developed to provide more comprehensive information, including the source associated with students' conceptions.

The five-tier diagnostic test in this study comprises an answer choice, a confidence level regarding the answer, a reason, a confidence level regarding the reason, and the source of the answer or reason. This structure enables researchers to distinguish between categories of conceptual understanding, lack of understanding, misconceptions, and errors, while also tracing the sources of misconceptions. Laliyo et al., (2023) demonstrated that sources of misconceptions can include textbooks, teachers, peers, the internet, or personal reasoning. Consequently, the use of a five-tier instrument not only provides information on the extent of misconceptions but also guides teachers in identifying specific areas of instruction that require improvement.

The urgency of this study is further highlighted by the initial situation at SMA Negeri 10 Pekanbaru. Interviews with the chemistry teacher revealed that the students' average score on the topic of acids and bases was 70, whereas the established learning mastery standard (KKTP) was 80. The teacher also observed conceptually incorrect response patterns, such as the belief that a lower pH value indicates a stronger acidic solution. Prior to this study, no specific identification of misconceptions had been conducted during the learning process. These conditions underscore the need for a more systematic overview of the nature and sources of these misconceptions.

While previous studies have examined acid-base misconceptions using two-tier, three-tier, and four-tier instruments, this study employs a five-tier approach to gather more comprehensive information regarding both the level of understanding and the sources of conceptions. The research focuses on Grade XI students at SMA Negeri 10 Pekanbaru who have already studied the topic of acids and bases. The study's novelty lies in the simultaneous mapping of five sub-concepts using the five-tier instrument and the integration of test results with interviews to strengthen the identification of misconception sources within the specific school context studied. Conceptually, this research is grounded in the view that diagnosing misconceptions requires an integrated consideration of answers, reasoning, beliefs, and the sources of conceptions.

Based on this premise, the study aims to identify specific sub-concepts within the acid-base topic where misconceptions occur among Grade XI students at SMA Negeri 10 Pekanbaru, as well as to identify the sources of these misconceptions specifically those linked to personal reasoning, textbooks, teachers, peers, and the internet. The findings are expected to provide diagnostic information that teachers can use to design concept reinforcement and remediation strategies better tailored to the nature of the students' misconceptions.

METHODS

This study employs a quantitative approach with a descriptive research design. This design was selected because the study aims to describe the state of students' misconceptions based on percentage data, without administering an experimental treatment. The research was conducted at SMA Negeri 10 Pekanbaru from February to July 2026, involving Grade XI students from the 2025/2026 academic year.

The study population consisted of 274 Grade XI students who had studied the topic of acids and bases. A sample of 163 students was selected using simple random sampling. The sample was drawn from students taught the acid-base material by the same subject teacher, ensuring that every member of the population had an equal chance of being selected. Additionally, 15 students were chosen via purposive sampling to participate in interviews, providing supplementary data.

The primary instrument was a 20-item, five-tier multiple-choice diagnostic test covering five sub-concepts: acid-base theories, acid and base strength, ionization equilibrium constants (Ka and Kb), pH levels, and acid-base indicators. The instrument was adapted from those developed or used by Febriana et al., (2025) and was subsequently modified and re-tested. Reliability testing yielded Cronbach's Alpha coefficients of 0.749 for the answer section and 0.638 for the reasoning section. Structured interviews were used to reinforce the interpretation of the sources of misconceptions.

Data were analyzed descriptively by categorizing responses based on combinations of answer choices, confidence in the answer, reasoning, and confidence in the reasoning. The categories used were: understanding the concept, not understanding the concept, misconception, and error. The percentage of misconceptions was calculated for each test item and averaged by sub-concept. Sources of misconceptions were traced via the fifth tier and categorized into books, teachers, personal reasoning, peers, and the internet. The criteria for misconception percentages were defined as low (0–30%), moderate (31–60%), and high (61–100%).

RESULTS

The research results indicate that the five-tier diagnostic test is capable of mapping students' levels of understanding across 20 test items regarding acid-base concepts. Overall, the misconception category accounts for the highest proportion, while the error category accounts for the lowest. The overall distribution of understanding categories is presented in Table 1.

Table 1. Percentage of Student Understanding Level Categories regarding Acid-Base Material

Category	Overall number/proportion (%)
Misconception (M)	46.29
Lack of conceptual understanding (TPK)	19.51
Conceptual understanding (KP)	27.21
Error (K)	6.99

Source: Processed data, 2026

Based on Table 1, the students' level of understanding regarding acid-base topics reveals that the misconception (M) category accounts for the highest percentage at 46.29%, followed by the conceptual understanding (KP) category at 27.21%, the lack of conceptual understanding (TPK) category at 19.51%, and the error (K) category at 6.99%. The high percentage of misconceptions indicates that nearly half of the students' understanding of acid-base topics involves concepts that do not align with scientific principles. Meanwhile, the percentage of students in the conceptual understanding category suggests that some have grasped acid-base concepts well, whereas the categories for lack of understanding and errors indicate that there are still students unable to comprehend the material or provide correct answers. Overall, these results demonstrate that misconceptions constitute the most dominant category of understanding regarding acid-base topics.

Table 2. Percentage of Student Misconceptions for Each Sub-concept of the Acid-Base Topic

Sub-concept	Average misconception (%)	Category
Acid-base theories (Arrhenius, Brønsted–Lowry, Lewis)	46.17	Moderate
Acid and base strength	43.40	Moderate
Ionization equilibrium constants (Ka and Kb)	48.77	Moderate
Degree of acidity (pH)	47.55	Moderate
Acid-base indicators	45.55	Moderate
Overall	46.29	Moderate

Source: Processed data, 2026

Based on Table 2, student misconceptions occurred across all sub-concepts of the acid-base topic, falling into the moderate category. The highest percentage of misconceptions was found in the ionization equilibrium constant (Ka and Kb) sub-concept at 48.77%, followed by the degree of acidity (pH) sub-concept at 47.55%, acid-base theory at 46.17%, acid-base indicators at 45.55%, and acid and base strength at 43.40%. These results indicate that misconceptions persist across all sub-concepts at relatively similar levels. Overall, the

percentage of misconceptions regarding the acid-base topic was 46.29%, placing it in the moderate category. These findings demonstrate that the ionization equilibrium constant (Ka and Kb) sub-concept exhibited the highest percentage of misconceptions compared to the other sub-concepts.

Table 3. Distribution of Sources of Student Misconceptions on the Topic of Acids and Bases

Source of misconception	Percentage (%)
Personal thinking	47.3
Books	16.8
Teachers	14.6
Friends	13.2
Internet	8.2

Source: Processed data, 2026

Based on Table 3, the primary source of student misconceptions regarding the topic of acids and bases is personal reasoning, accounting for 47.3%. Subsequent sources include textbooks (16.8%), teachers (14.6%), peers (13.2%), and the internet (8.2%). These results indicate that personal reasoning is the most dominant source of misconceptions compared to the others. This situation demonstrates that misconceptions are not solely linked to information students acquire from their learning environment; they can also arise from how students interpret and connect received information with their existing understanding. Meanwhile, the internet represents the source with the lowest percentage of misconceptions, at 8.2%.

Table 4. Distribution of Sources of Misconceptions Based on Sub-concepts

Sub-concept	Books (%)	Teachers (%)	Personal reasoning (%)	Friends (%)	Internet (%)
Acid-base theory	19.3	14.0	49.5	11.3	6.0
Acid and base strength	18.4	14.5	51.2	9.2	6.7
Ionization constants (Ka and Kb)	17.6	12.9	47.8	13.8	7.9
Degree of acidity (pH)	14.5	17.1	43.5	15.8	9.0
Acid-base indicators	13.8	14.8	43.4	16.5	11.5
Average	16.8	14.6	47.3	13.2	8.2

Source: Processed data, 2026

Based on Table 4, personal reasoning is the most dominant source of misconceptions across all sub-concepts of the acid-base topic. For the acid-base theory sub-concept, personal

reasoning accounts for 49.5%, followed by books (19.3%), teachers (14.0%), peers (11.3%), and the internet (6.0%). Regarding the acid and base strength sub-concept, personal reasoning is also the leading source at 51.2%, while books account for 18.4%, teachers 14.5%, peers 9.2%, and the internet 6.7%. For the ionization constant (Ka and Kb) sub-concept, personal reasoning reaches 47.8%, followed by books (17.6%), peers (13.8%), teachers (12.9%), and the internet (7.9%). Furthermore, for the degree of acidity (pH) sub-concept, personal reasoning stands at 43.5%, followed by teachers (17.1%), peers (15.8%), books (14.5%), and the internet (9.0%). In the acid-base indicator sub-concept, personal reasoning accounts for 43.4%, followed by peers (16.5%), teachers (14.8%), books (13.8%), and the internet (11.5%). Overall, the highest average source of misconceptions is personal reasoning (47.3%), while the lowest is the internet (8.2%). These results indicate that personal reasoning is the most consistent and dominant source of misconceptions across every sub-concept studied.

DISCUSSION

Research results indicate that student misconceptions regarding acid-base topics reached 46.29%, placing them in the moderate category. This finding implies that nearly half of the analyzed responses exhibited answer patterns and reasoning inconsistent with scientific concepts, accompanied by a conviction in the correctness of those answers. The proportion of students demonstrating conceptual understanding was only 27.21%, while 19.51% fell into the "lack of understanding" category and 6.99% into the "error" category. These patterns reveal that the primary issue is not merely a lack of knowledge but the presence of alternative conceptions held by the students.

The high prevalence of misconceptions can be attributed to the nature of acid-base topics, which integrate definitions, particulate representations, calculations, and mathematical relationships. Students cannot simply memorize definitions of acids and bases; they must understand proton transfer, ionization processes, the relationship of Ka and Kb values to acid-base strength, and how concentration changes affect pH. Laliyo et al. (2023) demonstrated that acid-base topics can be challenging due to the requirement for understanding abstract concepts. This situation creates a tendency for students to formulate simplified rules based on superficial features or prior experiences.

Regarding the acid-base theory sub-concept, a misconception rate of 46.17% indicates that students struggle to distinguish between the boundaries of the Arrhenius, Brønsted–Lowry, and Lewis theories. Question number 2 yielded the highest rate of misconception (56.44%) because students incorrectly identified the proton donor and acceptor within the NH_3 and HNO_3 pair. This was not merely a procedural error; interviews revealed a genuine belief among students that NH_3 acts as a proton donor. These findings align with those of Bakti et al. (2022), who reported that understanding acid-base theories remains a source of misconceptions in acid-base instruction.

The percentages observed in this study are higher than those reported by Faidzah et al. (2024) regarding the acid-base theory concept at two schools in Pekanbaru using a four-tier instrument. These differences may be attributed to student characteristics, the instruments used, learning experiences, and the scope of the indicators applied. Nevertheless, the study's findings consistently indicate that acid-base theory is a topic requiring conceptual diagnosis. The use of a five-tier instrument provides additional information regarding the sources of conceptions, enabling teachers not only to identify student errors but also to trace the potential origins of such understandings.

Regarding the sub-concept of acid and base strength, the prevalence of misconceptions was 43.40% falling into the moderate category which represented the lowest percentage among the five sub-concepts, albeit still a significant figure. A notable error occurred in question number 8 (52.76%), where students were asked to rank acid strengths based on Ka values; some students mistakenly believed that a smaller Ka value indicated a stronger acid. This pattern suggests that students failed to correctly link Ka values to ionization tendencies and H^+ ion concentrations. Utami et al., (2020) also identified student difficulties in determining acid and base strengths.

Regarding the sub-concept of ionization equilibrium constants (Ka and Kb), the misconception rate reached 48.77%, marking the highest level observed. This high rate indicates that the relationships between the variables involved in ionization equilibrium have not yet been fully grasped. Question number 12 resulted in a 52.15% misconception rate regarding the determination of a conjugate base's Kb based on Ka and Kw. Student responses revealed a tendency to apply simple proportional reasoning without understanding the mathematical relationship $Ka \times Kb = Kw$. This situation highlights the need for

instruction that emphasizes not only formula application but also the underlying meaning of the relationships between variables.

The misconception rate for the Ka and Kb sub-concept found here is lower than that reported by Anitasari et al., (2019), who found a 70% rate using a four-tier diagnostic test. These results are also lower than the findings of Ananda et al., (2025) across various school contexts in Pekanbaru. Variations in misconception levels may be attributed to student characteristics and the depth of instruction. Nevertheless, the high percentage observed in this study demonstrates that the concept of ionization equilibrium remains an area requiring further reinforcement.

For the sub-concept of acidity (pH), the misconception rate reached 47.55%. The highest error rate occurred in question number 15 (51.53%), which concerned the dilution of an HCl solution and the resulting pH change. Some students perceived pH changes as linear rather than logarithmic. This error indicates a failure to integrate the relationship between pH and H^+ ion concentration. Abdullah et al., (2020) similarly identified student difficulties regarding the understanding and calculation of acid-base solution pH.

Regarding acid-base indicators, the misconception rate reached 45.55%, with question number 19 showing the highest rate at 52.76%. Students were asked to link the pH data of various substances with litmus paper color changes. Errors in this section indicate that some students were unable to integrate concepts regarding acid-base properties, pH values, and the principles of indicator color changes. These findings align with those of Rumape et al., (2024), who identified misconceptions regarding acid-base indicators using a three-tier instrument.

An interesting finding of this study is that the primary source of misconceptions was students' own reasoning, accounting for 47.3%. This result suggests that students often construct their own explanations based on information they have received and subsequently maintain these explanations when answering questions. Suparwati, (2022) explain that alternative conceptions can arise from student reasoning that does not align with scientific concepts. Research interviews reinforced this, as some students explicitly stated that they selected answers based on their own understanding or recollection.

Textbooks were the second most common source, accounting for 16.8%. This source may be linked to how students read, comprehend, and utilize the examples or explanations provided in the books. Anitasari et al., (2019) demonstrated that the way

textbook content is presented can contribute to the emergence of misconceptions. In this study, the highest incidence of misconceptions linked to textbooks occurred within the acid-base theory sub-concept (19.3%). This indicates that reviewing the examples and explanations found in learning resources could be part of efforts to improve instruction.

Teachers were identified as the source of misconceptions in 14.6% of cases. This percentage does not imply that every teacher explanation leads to a misconception; rather, it indicates that some students associated their chosen erroneous conceptions with explanations or learning experiences provided by the teacher. Regarding the pH sub-concept, the teacher-related source reached 17.1%. Ananda et al., (2025) emphasized that the method of material delivery and the opportunities students have to express their ideas can influence the formation of incorrect understandings. Therefore, instruction needs to provide space for testing and clarifying students' conceptions.

Peers accounted for 13.2% of sources, while the internet accounted for 8.2%. Regarding acid-base indicators specifically, peers were the source for 16.5% of cases, whereas the internet was the source for 11.5%. These variations indicate that the sources of misconceptions are contextual and do not remain consistent across every sub-concept. Fajar et al., (2023) explain that information obtained from one's social environment without verification can lead to the formation of inaccurate understandings. Furthermore, internet usage requires the ability to select credible and reliable sources.

Theoretically, the research findings support the view that misconceptions should be understood as alternative knowledge structures that persist when students hold firm beliefs in those conceptions. Methodologically, the use of a five-tier instrument yields richer information than diagnostic methods relying solely on correct-incorrect answers. Laliyo et al., (2023) demonstrated that multi-tier tests can be used to both identify misconceptions and trace their underlying causes. In the context of this study, combining test data with interview results revealed that the sources students relied upon helped explain why erroneous conceptions were maintained.

A practical implication of this study is the need for teachers to use diagnostic results as a basis for designing activities that reinforce conceptual understanding. Such reinforcement should focus particularly on inter-conceptual relationships such as the links between acid-base theories and conjugate pairs, acid dissociation constants (Ka) and acid strength, Ka-Kb-Kw, pH, pH and ion concentration, and pH and indicator color changes.

Instruction can also provide opportunities for students to articulate their predictions, reasoning, and confidence levels before scientific concepts are formally established. Rokhim et al., (2023) have highlighted the importance of a conceptual change approach in addressing misconceptions.

This study is limited by its scope, as it was conducted at a single school, and by its descriptive design, which did not test the effectiveness of specific interventions aimed at correcting misconceptions. Interviews were also conducted with 15 students as supporting data; consequently, the experiences of the entire cohort of 163 students could not be described in depth through interviews. Future research could expand the study locations and the number of participants, develop five-tier instruments for other chemistry topics, and test remediation or conceptual change models based on the identified sources of misconceptions.

CONCLUSION

Misconceptions regarding acid-base topics among Grade 11 students at SMA Negeri 10 Pekanbaru, identified using a five-tier diagnostic test, fell into the moderate category with an overall prevalence of 46.29%. Misconceptions were found across all sub-concepts studied; the highest prevalence was observed in ionization equilibrium constants (Ka and Kb) at 48.77%, followed by pH (47.55%), acid-base theories (46.17%), acid-base indicators (45.55%), and acid-base strength (43.40%). The primary source of these misconceptions was students' own reasoning (47.3%), followed by textbooks (16.8%), teachers (14.6%), peers (13.2%), and the internet (8.2%). This study contributes by mapping misconceptions and their sources across five acid-base sub-concepts using a five-tier diagnostic test supplemented by interviews. These findings can serve as a basis for teachers to design concept reinforcement and remedial strategies tailored to the specific nature of the students' misconceptions. Future research is recommended to expand the school context, include a more diverse participant pool, and test conceptual change interventions aimed at reducing the identified misconceptions.

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