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Development of an Instrument to Map Acid–Base Misconceptions among High-Achieving Senior High School Students in Eastern Indonesia

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Abstract

Acid–base misconceptions remain a persistent challenge in high school chemistry, particularly among high-achieving students in Eastern Indonesia, where instructional strategies often emphasize procedural knowledge over conceptual understanding. Mapping these misconceptions is critical to designing differentiated remediation strategies that promote deep conceptual change. This study aims to map students' misconceptions by developing a diagnostic test instrument named the Acid–Base Misconception Diagnostic Test Instrument (IDM-AB). Research data were obtained through expert validation (three chemistry education experts) and empirical testing, analyzed descriptively using SPSS. Instrument validation included content, construct, and language validity, item analysis (difficulty and point-biserial correlation), and internal consistency reliability (Cronbach's alpha = 0.905). The classification of misconceptions was based on the Certainty of Response Index (CRI) with a cutoff of 2.5. The pilot test involved 121 students, and the final test was administered to 123 students. Results show: (1) the IDM-AB instrument meets both theoretical and empirical validity standards; (2) student misconception levels were distributed as follows: moderate (42.86%, 51 students), high (37.82%, 45 students), and low (19.33%, 23 students). Students with high misconceptions require intensive conceptual correction, while those with low misconceptions show potential for scientific conceptual change. This mapping provides a foundation for implementing targeted, concept-specific remediation strategies to address persistent alternative conceptions in acid-base chemistry.

Keywords: Instrument Development; Misconception; Acid–Base; Eastern-Indonesia

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INTRODUCTION

Understanding the concept of chemistry in chemistry education is crucial because chemistry is an abstract subject involving microscopic phenomena, symbolic representations, and mathematical reasoning. Many students struggle to connect these dimensions, which leads to misconceptions (Behmke et al., 2018; Gkitzia et al., 2020). In practice, students often face difficulties in understanding various chemistry concepts, especially when transitioning from observable macroscopic phenomena to submicroscopic explanations and symbolic equations (Slapnicar et al., 2018). Students' understanding of chemistry concepts that deviates from the widely accepted scientific concepts is referred to as chemical misconceptions (Hidayat, Irianti, & Faturrahman, 2020). Furthermore, Lestari et al. (2020) and Mubarak et al. (2020) state that misconceptions are views that contradict the relevant scientific concepts that have been agreed upon by experts (Sihalolo et al., 2021; Warsito, 2021; Rosita et al., 2020). Misconceptions are also the result of individuals' errors in interpreting, connecting, or explaining phenomena based solely on their reasoning (Izza et al., 2021).

(Atchia & Gunowa, 2025; Paillusson & Booth, 2025; Slapnicar et al., 2018) report that the main difficulty arises when students attempt to connect macroscopic phenomena with submicroscopic explanations. For example, students observe color changes or gas formation in chemical reactions but struggle to understand what occurs at the atomic or molecular level. Additionally, the use of chemical symbols in formulas or equations often causes confusion, especially without a proper understanding of the concepts behind the symbols. Misconceptions occur when students develop an understanding that contradicts the correct scientific concept. For instance, in the acid-base concept, students often believe that the higher the concentration of acid, the stronger the acid, while the strength of an acid is more dependent on its ability to release hydrogen ions. Misconceptions can also arise from discrepancies between students' everyday knowledge and more in-depth scientific theory, such as in the Brønsted-Lowry or Lewis acid-base theories (Dakic et al., 2025; Pinthong et al., 2022; Yik et al., 2023).

(Behmke et al., 2018; Shaafi et al., 2025) state that students build their understanding through experience and instruction, but this understanding is not always scientifically accurate. Misconceptions can stem from prior knowledge, everyday language, misleading textbooks, or ineffective teaching strategies. Therefore, students must become aware of scientific concepts and facts that reveal inaccuracies in their understanding. They must also practice establishing logical connections between facts and alternative views to overcome their misconceptions (Siska & Pagolongan, 2021). Moreover, misconceptions cannot be directly observed; therefore, proper diagnostic tools are needed to identify and prevent misconceptions from continuing (Suparwati, 2022; Nurul et al., 2021).

Acid-base chemistry is one of the most fundamental and conceptually rich topics in the high school chemistry curriculum. This topic is also one of the most misunderstood, involving various models (Arrhenius, Brønsted-Lowry, Lewis), abstract representations, and contextual applications. Previous studies have shown that students often experience misconceptions in key subtopics such as acid-base strength, neutralization, pH calculations, and understanding the difference between concentration and strength (Brandriet & Bretz, 2014; Shaafi et al., 2025). Misconceptions in this domain can hinder further learning in other important topics such as chemical equilibrium, titration, and organic chemistry (Rosenthal & Sanger, 2012; Smith, 2022). (Atchia & Gunowa, 2025; Behmke et al., 2018; Fu et al., 2025; Pinthong et al., 2022; Shaafi et al., 2025; Yik et al., 2023) state that most research on misconceptions in chemistry education reported in scientific journals has mostly been conducted in Western regions of Indonesia, with relatively few studies conducted in the eastern part of the country, particularly in Sumbawa. The educational context in Eastern Indonesia differs due to disparities in access to qualified teachers, laboratory facilities, and learning materials. Academics have consistently noted that student misconceptions are difficult to eliminate, especially in formal teaching contexts, as these misconceptions are often deeply ingrained in their prior knowledge and strong beliefs. If these misconceptions are not addressed properly, students will face significant challenges in assimilating new scientific concepts (Mubarak & Yahdi, 2020).

(Chen, 2024) states that this issue is even more critical among high-achieving students, where their performance in assessments may obscure the persistent misconceptions they hold. These students often rely on memory or algorithmic approaches to succeed in exams, even though they still maintain scientifically inaccurate views. This paradox makes them theoretically important in educational research, as their misconceptions may reflect alternative frameworks that are more robust. High-achieving students, despite achieving high scores in procedural or recall-based exams, may struggle with application and conceptual reasoning. Therefore, identifying and correcting their misconceptions is vital for promoting meaningful learning and scientific thinking (Chung & Kim, 2024; Faiman & Strouse, 2025).

(Ningroom et al., 2025; Rokhim et al., 2024a) highlight the importance of mapping students' misconceptions to enable remedial instruction and reduce their persistence, making it crucial to develop instruments to diagnose these misconceptions. Diagnostic assessment of misconceptions provides insight into students' understanding of the subject matter, helping teachers design appropriate interventions. Misconception diagnosis is especially critical in formative assessment contexts, where early detection allows for timely and personalized remediation strategies. These instruments must not only identify the presence of misconceptions but also distinguish between misconceptions that students strongly believe in, where they are deeply convinced of the wrong idea, and uncertainty, where students are guessing or unsure (Altan & Sener, 2023; Raharjo et al., 2019; Rokhim et al., 2024a, 2024b).

As an initial step, the researcher interviewed a chemistry teacher at SMAN 1 Sumbawa. The interview revealed that no diagnostic test for misconceptions had ever been implemented with students, resulting in the absence of specific instruments to identify misconceptions, particularly in the acid-base concept. Therefore, developing a diagnostic instrument for acid-base misconceptions is crucial so that teachers can use it to detect misconceptions among high school students in Sumbawa. Although misconceptions are often difficult to correct, early detection allows for timely prevention, as misconceptions can occur in any group of learners, including high-achieving students in Sumbawa (Suyono, 2020). Previous research reported that students often experience misconceptions in several fundamental acid-base chemistry subtopics, such as the development of the acid-base concept (14.52%); acid-base solutions (75.81%); neutralization reactions (48.79%); acid-base strength (31.45%); and the difference between strong and weak acids (66.13%) (Mubarak & Yahdi, 2020; Suparwati, 2022; Lestari et al., 2020; Izza et al., 2021; Siska & Pagolongan, 2021; Nugroho et al., 2019; Turkoguz, 2020). Based on the conceptual analysis and literature review of the most vulnerable subtopics to misconceptions, the researcher has identified the acid-base subtopics to be developed into diagnostic instruments, including the Arrhenius acid-base theory, Brønsted–Lowry acid-base theory, acid-base indicators, acid-base strength, and pH. It is expected that students will show a higher level of misconception, especially in subtopics such as acid-base solutions and the difference between strong and weak acids, based on previous reports indicating persistently high levels of misconception.

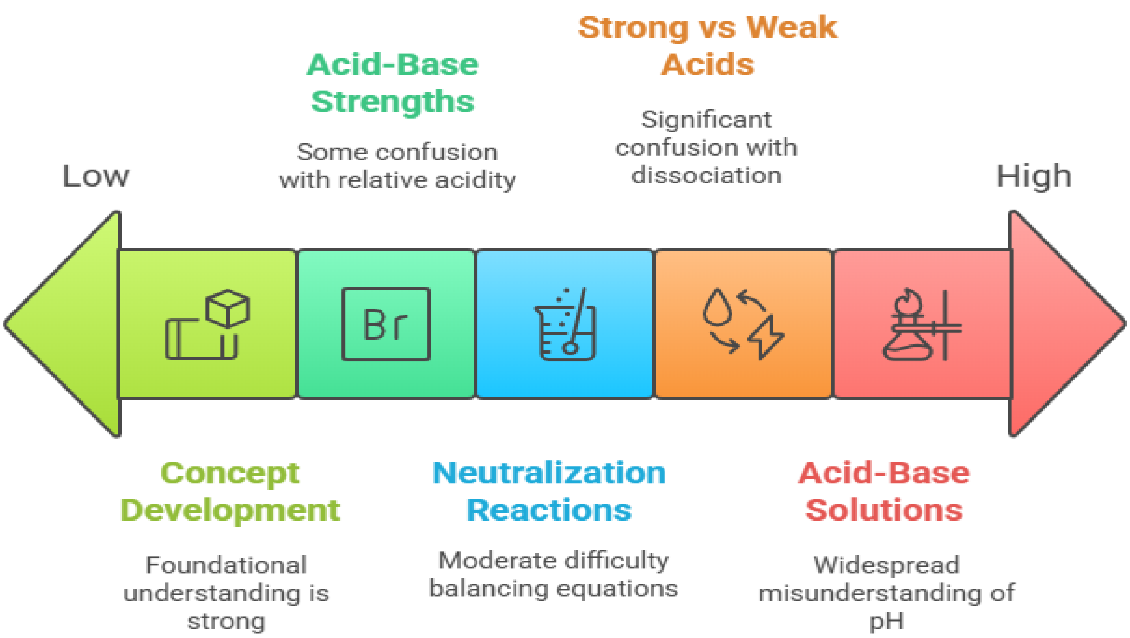

Figure 1. Diagram of Student Understanding Levels on Acid-Base Concepts

This diagram uses a horizontal scale divided into four parts representing the progression of understanding from low to high. Acid-Base Strengths: The first section shows a low level of understanding, with confusion related to the relative nature of acids and bases, as well as difficulty in distinguishing between strong and weak acids. Neutralization Reactions: In the middle section, there is a greater challenge in balancing neutralization reaction equations, but a basic understanding of these concepts starts to become stronger. Acid-Base Solutions**:** The far-right section indicates that students' understanding of acid-base solutions tends to be weak, with widespread misconceptions related to pH. This scale displays the relationship between concept comprehension, challenges in equation balancing, and students' difficulties in grasping acid-base concepts, providing an overview of how misconceptions develop across various levels of understanding (Altan & Sener, 2023; Shaafi et al., 2025; Suparman et al., 2024).

Misconceptions about acid-base concepts remain diverse and uneven among individuals and subtopics. This issue becomes more pronounced among students in Eastern Indonesia, who have never been assessed using diagnostic misconception tests. To more accurately identify the distribution of these misconceptions, it is crucial to develop a specific instrument that can map students' misconceptions in detail. (Tian et al., 2022; Vernon & Dunphy, 2025) report that the geographical location of a region can influence individuals' thinking patterns and potentially lead to misconceptions. Communities living in rural areas often face simpler, everyday problems directly related to visible aspects of life, such as agriculture and survival. As a result, they tend to have a more practical and concrete mindset, focusing more on direct solutions without considering the complexities of the problems (Artvinli & Dönmez, 2020; Mikander & Satokangas, 2025). On the other hand, urban communities deal with much more complex issues, such as social, economic, and technological concerns that are interconnected. These problems require more abstract, analytical thinking and often involve multiple perspectives. Therefore, people living in cities tend to have a more complex thinking system and are more open to various solutions and approaches (Candiasa et al., 2025). This difference can lead to misconceptions, especially when someone from a rural area tries to apply a simpler mindset to more complex problems in urban areas, or vice versa. The lack of experience or understanding of the complexities of a problem can result in misunderstandings that hinder effective problem-solving.

Based on the issues mentioned, this research aims to develop an instrument to map acid-base misconceptions among high-achieving high school students in Sumbawa. Misconceptions require special attention in education to ensure that students' understanding aligns with the scientific consensus. Therefore, the research questions for this study are: (1) To what extent is the instrument developed deemed feasible based on expert evaluation? and (2) What can be discovered from the misconception mapping of students in high-achieving high schools in Eastern Indonesia, specifically in Sumbawa Regency?

The objectives of this study are: (1) to develop and produce a valid diagnostic instrument, namely the Acid-Base Misconception Diagnostic Instrument (IDM-AB)**,** based on expert evaluation; and (2) to map students' misconceptions based on three criteria: students with high levels of misconception, students with moderate levels of misconception, and students with low levels of misconception. The misconception map produced can then be used to reduce misconceptions by applying conceptual change strategies or other effective teaching approaches.

Existing diagnostic instruments, including two-tier and four-tier tests, have been widely used to assess students' conceptual understanding in chemistry. However, these instruments often require lengthy administration times and may be difficult for teachers to interpret at the subtopic level. The IDM-AB instrument integrates the Certainty of Response Index (CRI) framework, which allows teachers to distinguish between misconceptions strongly believed by students and a lack of knowledge. This feature enhances the practical utility of the instrument for classroom interventions. Additionally, the distractors in IDM-AB are carefully constructed based on documented alternative conceptions, providing a solid foundation for diagnosing misconceptions. Unlike traditional instruments, IDM-AB emphasizes efficient administration, clear categorization of misconception levels, and detailed mapping at the subtopic level, making it a valuable tool for instructional planning.

METHOD

Research Design

The type of research employed in this study was Research and Development (R&D). The study aimed to produce a product, examine its quality, and map students' misconceptions using the developed instrument. The development of such an instrument was a prerequisite for mapping misconceptions. The resulting product was an instrument designed to measure misconceptions among senior high school students, named the Acid–Base Misconception Diagnostic Instrument (IDM-AB). The IDM-AB enabled the identification of students who held misconceptions, had accurate conceptions, or demonstrated a lack of understanding for each tested concept. Furthermore, students' misconceptions were categorized into three levels: high, moderate, and low.

The quality of the IDM-AB was then evaluated in terms of: (1) construct validity, content validity, and linguistic clarity of the test items; (2) item difficulty and reliability of the test instrument; and (3) practicality and effectiveness. The research model adapted Borg and Gall's (2007) R&D procedure into five stages: (1) product analysis, (2) initial product development, (3) product validation, (4) product revision, and (5) field testing.

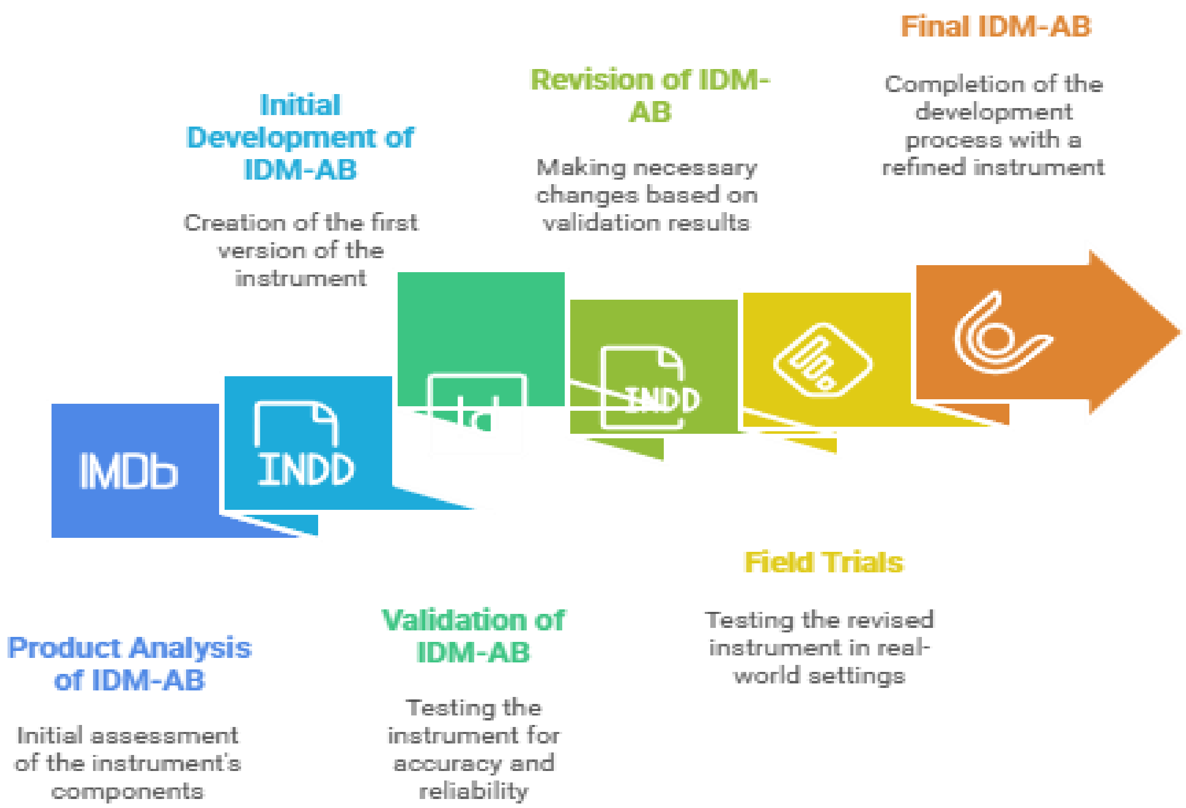

Figure 2. Stages of Development for the Acid-Base Misconception Diagnostic Instrument (IDM-AB)

Research Instrument

The instrument developed, IDM-AB, consisted of multiple-choice questions with five answer options, each accompanied by a certainty of response index (CRI). This approach required students not only to select an answer but also to indicate their level of confidence, thereby providing deeper insights into their cognitive understanding. Content validation was conducted through expert judgment, involving chemistry education experts from universities as well as chemistry teachers from schools. A structured validation sheet was provided for experts to give feedback, which was then used to revise and refine the instrument.

The CRI method, introduced by Hasan et al. (1999), was used to help teachers identify students' misconceptions. According to Hasan et al., CRI is a measure of students' confidence in their answers to test items. Similarly, Izza et al. (2021) and Muna (2016) emphasized that CRI requires students to indicate their confidence levels based on their ability to process conceptual knowledge, laws, and principles. Each response option in CRI reflects the degree of confidence in the correctness of the chosen answer, as shown in Table 1.

Table 1. Student Confidence Index (CRI) in Answering Conceptual Questions

CRI Scale	CRI Criteria	Category	
		T	F
0	Totally Guessed Answer (100% guessing)	DK	DK
1	Almost Guess (76–99% guessing)	DK	DK
2	Not Sure (50–75% guessing)	DK	DK
3	Sure (25–49% guessing)	KC	MC
4	Almost Certain (1–24% guessing)	KC	MC
5	Certain (0% guessing)	KC	MC

Notes: T = True; F = False; DK = Don't Know Concept; KC = Know Concept; MC = Misconception.

Based on Hasan et al. (1999), students' conceptions using the CRI method are categorized as "know concept," "don't know concept," or "misconception," as presented in **Table 2**.

Table 2. Criteria for Determining Students' Conceptual Status Based on CRI

Answer Criteria	Low CRI Index (≤ 2.5)	High CRI Index (≥ 2.5)
Correct Answer	Don't Know Concept	Know Concept
Incorrect Answer	Don't Know Concept	Misconception

A low CRI score indicates weak conceptual certainty, often reflecting random guessing, while a high CRI score demonstrates strong confidence in conceptual understanding. The distinction between "misconception" and "don't know concept" can thus be made by comparing students' correctness of answers with their CRI levels.

Data Collection

Data were collected through expert judgment on the developed instrument (assessing construct validity, content validity, and linguistic clarity) and through trials of the validated test instrument with students. Expert validation used a specially designed validation sheet developed by the researchers.

Data Analysis

Expert Judgment Data

Before the instrument was administered to students, validation by experts was conducted. The validation process evaluated construct validity, content validity, and linguistic clarity of the multiple-choice test items with CRI. This stage involved two subject matter experts and one practitioner, following criteria for determining test item feasibility. The feasibility scores were summed and converted into percentages using the following formula:

$$P(\%) = \frac{Total\ score\ obtained}{Maximum\ possible\ score} x100\%$$

The percentages were then interpreted using Arikunto's categorization (Putriawati, 2016), as presented in Table 3.

Table 3. Interpretation Categories for Validation Percentage

Category	Scale	Percentage
Very Valid	4	76–100%
Valid	3	56–75%
Fairly Valid	2	40–55%
Less Valid	1	<40%

Student Trial Data

Following expert validation, the instrument was piloted with students in two phases. The first trial was conducted with 121 students from SMAN 2 Sumbawa using cluster sampling. This stage aimed to evaluate construct validity (item validity), item difficulty, and instrument reliability using SPSS. After the instrument was confirmed to be valid and reliable, a second (final) trial was carried out with 123 students at SMAN 1 Sumbawa, one of the top-performing schools in Eastern Indonesia, particularly in Sumbawa Regency.

The final trial results were used to map students' conceptual understanding into three categories: misconception, don't know concept, and know concept. Furthermore, students' misconception loads were classified into high, moderate, and low levels.

RESULTS AND DISCUSSION

Data from Experts through Expert Judgment

The first research finding concerns the **construct validity** of the acid–base misconception diagnostic test instrument, which was validated by three chemistry experts. The results of the construct validation are presented in **Table 4**.

Table 4. Validation Results of the Acid–Base Misconception Diagnostic Instrument

No Item	Validator 1	Validator 2	Validator 3	%	Criteria
1	3	4	2	75	Valid
2	4	4	3	92	VeryValid
3	4	3	4	92	Very Valid
4	3	4	2	75	Valid
5	4	4	4	100	Very Valid
6	4	4	3	92	Very Valid
7	4	4	4	100	Very Valid
8	4	4	4	100	Very Valid
9	4	4	4	100	Very Valid
10	4	4	4	100	Very Valid
11	4	4	4	100	Very Valid
12	4	2	4	83	Very Valid
13	4	4	4	100	Very Valid
14	4	2	4	83	Very Valid
15	4	4	4	100	Very Valid
16	4	3	4	92	Very Valid
17	4	4	4	100	Very Valid
18	4	3	4	92	Very Valid
19	4	3	4	92	Very Valid
20	4	3	4	92	Very Valid

Based on the data in Table 4, the following analysis can be drawn: (a) considering the score percentages for each item, all 20 items were judged as valid by the three validators. This indicates that the developed items can be reliably used to measure indicators of students' understanding of acid–base concepts. This finding aligns with Arikunto (2010), who stated that percentages ranging from 75% to 100% are classified as valid to very valid; thus, the validated items can be used in further analysis. (b) The developed acid–base misconception diagnostic test has therefore met the construct validity criteria as a measurement tool for mapping students' chemistry misconceptions.

The results of the content validity and linguistic clarity review by the three validators indicated that there were no conceptual inaccuracies, and the items were written in clear and concise language.

Student Trial Data

First Trial

The analysis of data from the first trial showed that all items were valid and could therefore be used in mapping students' misconceptions. The difficulty index and validity values for the 20 items are presented in Table 5.

Table 5. Difficulty Index and Validity Values of the Student Misconception Diagnostic Instrument

Item	Difficulty Index	Criteria	Validity Value	Criteria
1	0.12	Difficult	0.48	Valid
2	0.15	Difficult	0.48	Valid
3	0.19	Difficult	0.46	Valid
4	0.03	Difficult	0.57	Valid
5	0.50	Moderate	0.64	Valid
6	0.43	Moderate	0.51	Valid
7	0.62	Moderate	0.75	Valid
8	0.51	Moderate	0.61	Valid
9	0.22	Difficult	0.68	Valid
10	0.25	Difficult	0.50	Valid
11	0.45	Moderate	0.72	Valid
12	0.02	Difficult	0.61	Valid
13	0.82	Easy	0.46	Valid
14	0.61	Moderate	0.65	Valid
15	0.65	Moderate	0.68	Valid
16	0.05	Difficult	0.57	Valid
17	0.57	Moderate	0.72	Valid
18	0.45	Moderate	0.64	Valid
19	0.11	Difficult	0.60	Valid
20	0.02	Difficult	0.70	Valid

Notes: DI (Difficulty Index); Difficult (0.00-0.30); Moderate (0.31-0.70); Easy (0.71-1.00)

The analysis in Table 5 shows that among the 20 valid items, 10 items were classified as difficult, 9 items as moderate, and 1 item as easy. The higher proportion of difficult items compared to moderate and easy items aligns with the researcher's expectation, as the test was specifically designed for screening students' misconception loads. All 20 items were therefore retained for the mapping stage.

The validity of each item was determined based on students' test scores using Pearson's point-biserial correlation. An item was considered valid if the calculated correlation coefficient (r_{hitung}) exceeded the critical value of Pearson's r (r_{tabel}) at $\alpha = 0.05$. For $N = 121$, $r_{tabel} \approx 0.178$ (Herlanti, 2006; Bonett, 2020). The analysis confirmed that all 20 items were valid.

The reliability analysis of the instrument (Table 6), based on Cronbach's Alpha using SPSS with responses from 121 students and 20 items, yielded r = 0.905. This indicates that the instrument met the reliability standard, thus demonstrating internal consistency for measuring students' conceptual understanding.

Table 6. Reliability test

Cronbach's Alpha	N of Items
.905	20

Final Trial

The final stage of the research involved mapping students' misconception loads using a sample of 123 students from SMAN 1 Sumbawa, one of the leading schools in Eastern Indonesia, specifically in Sumbawa Regency. The distribution of students' conceptual status (knowing concept, not knowing concept, and misconception) is shown in **Figure 1**. Misconception loads were classified into three levels: high, moderate, and low, based on the calculated mean and standard deviation.

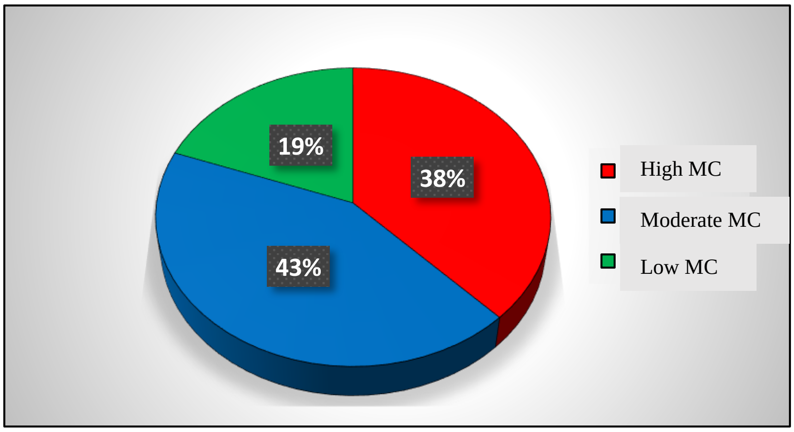

Figure 3. Pie Chart of Students' Misconception Loads

The results in Figure 1 can be summarized as follows: (a) Students' misconceptions were distributed across various acid–base concepts, with no uniform pattern across individuals. (b) Out of 123 students, 4 students had no misconceptions; thus, misconception mapping was carried out for the remaining 119 students. (c) Of these, 45 students (37.82%) had high misconception loads, requiring serious attention for remediation; 51 students (42.86%) had moderate misconception loads, forming the majority group; and 23 students (19.33%) had **low** misconception loads, which can be considered as having strong potential for conceptual change.

This heterogeneous distribution of misconceptions across acid–base concepts reflects the finding that one student's misconception does not necessarily occur in another, even on the same concept. This result is consistent with previous studies using diagnostic instruments (e.g., two-tier and four-tier tests), which reported that acid–base misconceptions are distributed heterogeneously across concepts and students; a student with a misconception in concept A does not necessarily exhibit the same misconception in concept B (Potvin, 2020; Suparman et al., 2024; Nahadi et al., 2023).

CONCLUSION

Based on the findings and discussion of this study, the following conclusions can be drawn: (1) the acid–base misconception diagnostic test instrument developed in this research met both theoretical validity requirements (construct, content, and linguistic validity) and empirical validity; (2) the students' misconception map revealed that: (a) 45 students, or 37.82% of the sample, demonstrated a high misconception load, indicating that these students require intensive attention and remediation to address their conceptual errors; (b) 51 students (42.86%) exhibited a moderate misconception load, representing the majority group in this study. These students did not show a distinctive pattern of misconceptions that could be directly used as a basis for designing remedial strategies; and (c) 23 students (19.33%) showed a low misconception load. These students, identified in the “green category,” are interpreted as having a high potential for conceptual change, making them more likely to successfully reconstruct their misconceptions into scientifically accurate conceptions.

RECOMMENDATION

Based on the results of this study, the following recommendations are proposed: (1) the students’ misconception map can be utilized by teachers and educators as a basis for planning remedial instruction grounded in conceptual change strategies; (2) students with high, moderate, and low misconception loads should be treated differently in efforts to reconstruct their misconceptions; and (3) the misconception map can serve as a valuable resource for enriching the body of knowledge in education, both for the present researchers and for future studies aimed at developing new research ideas.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Wiwin Putriawati,	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓
S. H. Chiani		✓	✓			✓		✓	✓	✓	✓			

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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