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Analysis of Conceptual Understanding of Acids and Bases: A Literature Review

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Abstract: Through an analytical synthesis comparing similarities and differences across various studies, this literature review identifies research trends dominated by qualitative approaches among Grade XI students with a focus on acids and bases, as well as multilevel diagnostic instruments for student misconceptions in chemistry. The review highlights research gaps in the integration of multilevel chemical representations, acknowledges the limitations of prior studies that remain largely descriptive without comprehensive conceptual mapping, and proposes future research directions in the form of evidence-based pedagogical interventions to address student misconceptions about acids and bases. This situation is further compounded by the dominance of rote-learning methods that neglect deeper understanding at the submicroscopic level. Therefore, the instructional approach recommended is the integration of guided inquiry, which is capable of bridging students' understanding from the macroscopic to the submicroscopic perspective through technology-based simulations and laboratory experiments.

Keywords: conceptual understanding, acids and bases, misconceptions, literature review, chemistry learning

Abstrak: *Pemahaman konsep asam dan basa masih menjadi tantangan dalam pembelajaran kimia karena materi ini bersifat abstrak dan melibatkan representasi makroskopis, submikroskopis, dan simbolik. Berbagai penelitian menunjukkan bahwa peserta didik pada berbagai jenjang pendidikan masih mengalami miskonsepsi dan kesulitan dalam memahami konsep pH, indikator, serta kekuatan asam dan basa. Penelitian ini bertujuan untuk menganalisis tingkat pemahaman konsep asam dan basa, bentuk kesulitan yang dialami peserta didik, serta faktor-faktor yang memengaruhinya berdasarkan kajian literatur. Metode yang digunakan adalah kajian literatur dengan pendekatan kualitatif melalui analisis berbagai artikel ilmiah yang relevan. Hasil kajian menunjukkan bahwa rendahnya pemahaman konsep dipengaruhi oleh faktor internal peserta didik, metode pembelajaran yang konvensional, keterbatasan media, dan sifat abstrak materi. Oleh karena itu, penerapan pembelajaran inkuiri, media interaktif, dan instrumen diagnostik dinilai efektif untuk meningkatkan pemahaman konsep peserta didik.*

Kata Kunci: *pemahaman konsep, asam dan basa, miskonsepsi, kajian literatur, pembelajaran kimia*

INTRODUCTION

The concepts of acids and bases constitute a fundamental pillar of chemistry, underpinning the understanding of numerous natural phenomena and industrial processes. This topic is hierarchical in nature, requiring a firm conceptual grasp in order to comprehend advanced topics such as salt hydrolysis and buffer solutions (Thabiea, 2019). At both the university and senior high school levels, however, acid-base material is frequently regarded as difficult because it involves three levels of chemical representation: macroscopic, microscopic, and abstract symbolic (Lestari et al., 2023). A common phenomenon is that students tend to adopt rote-learning methods to memorise definitions without being able to internalise the conceptual essence in a meaningful way. This condition is supported by empirical findings across the literature, which consistently show that students' level of conceptual understanding of this topic remains relatively low. Research by Lestari et al. (2020) revealed that failure to construct understanding at the molecular level is often the root cause of students' low chemistry literacy. Furthermore, Izza et al. (2021) identified significant misconceptions, particularly regarding the sub-concepts of acidity (pH) and acid strength, indicating that students' understanding often remains at a surface level without a comprehensive grasp of chemical logic.

Based on the gap between curriculum demands and the realities of conceptual understanding in the classroom, the primary problem investigated in this study is directed at an in-depth analysis of students' understanding of acid-base concepts through a comprehensive literature review. Although studies on learning difficulties and acid-base misconceptions have been conducted to some extent, comprehensive analyses synthesising these findings into a coherent conceptual map remain very limited. With respect to research gaps and the contribution of this review: the majority of prior literature has focused solely on identifying student errors within particular geographical areas or educational levels without conducting multi-literature comparisons to examine misconception patterns globally. This is precisely where the novelty of the present study lies. This literature review not only summarises past findings but also fills this gap by integrating data from various empirical studies to map which acid-base sub-concepts are most vulnerable to conceptual degradation, and by connecting them multidimensionally to the three levels of chemical representation. The primary contribution of this review is the provision of a critical synthesis that explicitly reveals both internal (psychological or cognitive) and external (pedagogical or curricular) determinants that impede learning. This study therefore aims to present a data synthesis on the current profile of acid-base conceptual understanding in order to map the concepts that students find most difficult, and further to evaluate the factors that hinder student learning. The findings of this analysis are expected to make both theoretical and practical contributions to the development of more effective science learning strategies in the future.

METHODS

This study employed a literature review method with a qualitative approach. According to Creswell (2017), the qualitative approach is used to explore and understand the meanings attributed by individuals or groups to a social problem or particular phenomenon. In this study, the literature review was conducted to analyse and synthesise the findings of prior research studies in order to obtain a comprehensive picture of the level of conceptual understanding of acids and bases, the forms of misconceptions, their contributing factors, and strategies for improving conceptual understanding. The article search was carried out through several scientific databases: Google Scholar, Garuda, and Semantic Scholar. Literature searches were conducted using Boolean keyword combinations such as "pemahaman konsep" AND "asam basa", "acid-base concept understanding" AND "misconception", "miskonsepsi asam basa", and "chemistry learning" AND "acid base". Articles searched were limited to scientific publications from 2018 to 2025.

An initial search yielded 52 articles. A screening process was subsequently carried out based on the relevance of the title, abstract, article content, and alignment with the research focus. The inclusion criteria were: (1) the article addresses conceptual understanding or misconceptions on acid-base material; (2) the article is an indexed scientific journal or proceedings; (3) the article was published between 2018 and 2025; and (4) the article is available in full text. The exclusion criteria were: (1) articles not relevant to the research topic; (2) duplicate articles; and (3) articles that discuss chemistry learning in general without a specific focus on acid-base material (Page et al., 2021; Snyder, 2019).

Following the selection process, 30 articles were obtained for use as the primary sources of the study. The literature review procedure was carried out through several stages: article identification, article selection, content review, thematic grouping, and synthesis of research findings. The data analysis process employed thematic synthesis, which grouped the research findings into four main themes: (1) the level of acid-base conceptual understanding; (2) the forms of misconceptions and learning difficulties; (3) factors affecting conceptual understanding; and (4) learning strategies for improving conceptual understanding.

The article selection process in this study adapted a simplified Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow comprising the stages of identification, screening, eligibility, and inclusion. The synthesised literature was then analysed descriptively and comparatively to identify similarities, differences, research trends, and research gaps related to acid-base conceptual understanding.

RESULTS AND DISCUSSION

Result

Table 1. Summary of Findings from the Literature Review

Author & Year	Research Focus	Method	Subject	Main Findings	Research Implications
A. Elementary Science Education (SD/MI)					
Ramadani et al. (2026)	Innovation of discovery learning in elementary science	Qualitative CAR	Elementary school students	Strong understanding on identification; weak on classification & inference	Need for inquiry-based scaffolding from elementary level
Fabilla et al. (2023)	Misconceptions in Grade IV elementary science	Three-tier test	34 Grade IV students	Overgeneralisation misconceptions on acid/base properties from daily experience	Experiment-based conceptual remediation
Kasanah & Setiyawati (2024)	Elementary misconceptions via CRI	CRI + written test	State elementary students	54.1% of students experienced misconceptions in science including acid-base concepts	Early misconception detection should be carried out routinely
Hasnawati et al. (2022)	Science conceptual understanding of prospective elementary teachers	Concept test, survey	PGSD students	Some prospective elementary teachers held inaccurate science conceptions	Strengthening science content in teacher education curricula
Dewi & Ibrahim (2019)	Elementary misconceptions and the importance of remediation	Conceptual review	Elementary students	Students assess substances based on taste/appearance rather than chemical properties	Experience-based concrete and scientific learning
Alfiani & Fazila (2025)	Discovery learning + puzzle for Grade V science	Quasi-experiment	Grade V students	Puzzle media significantly improved science conceptual understanding	Manipulative media effective for abstract concepts at elementary level
Khofifah et al. (2024)	PjBL in Merdeka Curriculum	Qualitative CAR	Elementary students	PjBL improved conceptual understanding	PjBL effective in the Merdeka Curriculum context

	elementary IPAS			from cycle 1 to cycle 2	
Margunayasa et al. (2021)	Guided inquiry reduces elementary misconceptions	RCT experiment	Elementary students	Guided inquiry significantly reduced science misconceptions	Inquiry models need to be integrated from elementary level
Aiman et al. (2020)	POGIL + realia media in elementary school	Experiment	Elementary students	POGIL improved scientific literacy and critical thinking	Local realia effective as contextual media
Ananda et al. (2024)	Turmeric litmus paper media in elementary school	CAR	Elementary students	Significant improvement in learning outcomes on acid-base material	Nature-based media increases learning motivation
B. Secondary Chemistry Education (SMP/SMA)					
Nugraha et al. (2026)	Acid-base misconceptions at 3 representational levels	Three-tier + interview	52 SMA students	Misconceptions occur simultaneously at macro, submicro, and symbolic levels	Multiple representation-based instruction is greatly needed
Febriana et al. (2025)	Acid-base misconceptions via five-tier test	Five-tier diagnostic	SMA students	73.44% of misconceptions stem from students' own personal thinking	Mapping misconception sources for targeted remediation
Laliyo et al. (2023)	Acid-base misconceptions via two-tier	Two-tier test	SMA students	Mean misconception rate 64.44%; highest on amphoteric concept (85.31%)	Need for comprehensive diagnostic instruments across sub-concepts
Naz & Mushtaq (2022)	Conceptual difficulties in acid-base SMA	Survey, concept test	Pakistani SMA students	60% of acid-base conceptual items categorised as difficult	Active learning based on contextual problem-solving
Azizah et al. (2022)	Cross-level acid-base misconceptions	Two-tier + interview	SD, SMP, SMA students	Acid-base misconceptions are persistent and found across all education levels	Building correct conceptual foundations from elementary level is critical
Rumape et al. (2024)	Conceptual understanding of acid-base titration	Literature review	Grade XI SMA students	Acid-base titration is the most difficult sub-topic at SMA level	Integration of conceptual, mathematical, and procedural skills
Irnananda et al. (2024)	PIRPOSAL model and	Quasi-experiment	SMP students	Science attitude significantly affects	Collaborative model improves motivation and

	science attitude in SMP			conceptual understanding	scientific attitude
Rasid et al. (2020)	Guided inquiry vs direct instruction	Quasi-experiment	SMA students	Both significant; inquiry more effective for deep understanding	Model selection should match context and student characteristics
Muchlis (2022)	Guided inquiry and critical thinking skills	CAR	SMA students	Guided inquiry improved critical thinking on acid-base material	Inquiry model optimises construction of understanding
Zuhroti et al. (2018)	Understanding at 3 representational levels	Diagnostic test	SMA students	Strong understanding at macroscopic level; weak at submicroscopic and symbolic	Instruction must integrate all three representational levels
Nurani & Suyanta (2024)	Inquiry-based multiple representation teaching materials	R&D	SMA students	Inquiry-based MR teaching materials effectively improve understanding	Multiple representation needs to be integrated into teaching materials
Redhana et al. (2020)	Mental models of acid-base in SMA students	Conceptual review	SMA students	Students' mental models do not match correct scientific concepts	Instruction needs to bridge mental models with scientific concepts
Lestari et al. (2021)	REACT model and conceptual understanding in SMA	Quasi-experiment	Grade XI SMA students	REACT significantly improved chemistry conceptual understanding	Contextual learning effective for abstract chemistry content
C. Higher Chemistry Learning (Perguruan Tinggi)					
Rokhim et al. (2023)	Misconception analysis and chemistry diagnostic instruments	PRISMA literature review	Multi-level	Three-tier test most effective for detecting chemistry misconceptions	Three-tier test recommended as the standard diagnostic instrument
Fariza et al. (2025)	Cross-concept science misconceptions in SD	Observation case study	Grade VI students	Acid-base is the topic with the highest misconceptions across concepts	Structured and sustained curricular intervention is needed
Fathonah et al. (2024)	Chemistry conceptual understanding across studies	Literature review	Multi-level	Chemistry conceptual understanding generally low across all educational levels	Systemic reform of chemistry pedagogy is required

Soeharto & Csapo (2021)	Difficulty level of science diagnostic items across concepts	Psychometric analysis	Students and teachers	Acid-base consistently ranks as the most difficult topic across science concepts	Special instructional priority needed for acid-base topics
Musyadi et al. (2025)	AR media and chemistry conceptual understanding	Literature review	Multi-level	AR consistently improves understanding of abstract chemistry concepts	AR has great potential to address submicroscopic visualisation difficulties
Izza et al. (2021)	Acid-base misconceptions via CRI + essay test	Quantitative descriptive	Chemistry students	Significant misconceptions on pH and acid strength sub-concepts	Scientific conception-based remediation needed for university students
Irawati (2019)	Effect of acid-base understanding on hydrolysis	Correlational	Grade XI SMA students	Acid-base understanding positively affects understanding of salt hydrolysis	Strengthening foundational acid-base concepts impacts advanced topics

Table 1 presents a synthesis of 27 scientific articles reviewed in this study, grouped by three educational levels: (A) Elementary Science Education (SD/MI), (B) Secondary Chemistry Education (SMP/SMA), and (C) Higher Chemistry Learning (university/multi-level). Each article was analysed across six aspects: author and year of publication, research focus, research method, research subject, main findings, and research implications. The synthesised articles were sourced from indexed scientific journals retrieved through the Google Scholar database, covering publications from 2018 to 2026. Article selection was based on topical relevance to acid-base conceptual understanding, alignment with the research objectives, and the availability of sufficient methodological information for comparative analysis. This table serves as the comprehensive literature map that underpins all analysis and discussion in this study.

Discussion

Elementary Science Education

Research on acid-base conceptual understanding at the elementary school level (SD/MI) consistently finds that the majority of students have not yet achieved adequate understanding. This condition is not solely attributable to children's cognitive limitations but rather to the complex interaction among the abstract nature of the material, teacher competency, and the limited range of instructional strategies employed. This review presents an integrated profile of understanding, misconceptions, contributing factors, and improvement efforts at the elementary level.

Level of Conceptual Understanding

The literature review indicates that elementary school students are generally only able to understand acid-base concepts at the surface learning level that is, identifying and providing examples based on sensory experience but encounter difficulty with more complex aspects. Ramadani et al. (2026) found that elementary students' ability to identify and give examples was reasonably adequate, but their ability to classify, interpret, and draw scientific conclusions was still very weak. Kasanah and Setiyawati (2024) confirmed this finding with empirical data showing that only 45.8% of students had correct conceptual understanding, while 54.1% held misconceptions.

This indicates that more than half of elementary students carry inaccurate understanding of the properties of substances including acids and bases into subsequent learning.

Forms of Misconceptions and Difficulties

Misconceptions at the elementary level are generally overgeneralisations rooted in everyday sensory experiences that have not been scientifically constructed through instruction. Fabilla et al. (2023) documented two of the most common misconception patterns: (a) "all sour-tasting substances are necessarily harmful", and (b) "basic substances always feel slippery to the touch". Both patterns represent excessive generalisations from empirical experience that have not been corrected through inquiry-based learning. Dewi and Ibrahim (2019) added that elementary students tend to judge the properties of a substance based on its physical appearance or taste for example, "acidic substances are always dangerous to drink" without understanding the underlying chemical basis. This phenomenon is compounded by the finding of Hasnawati et al. (2022) that some prospective elementary teachers also hold inaccurate conceptions of the properties of acids, bases, and salts, making the transmission of misconceptions from teacher to student highly probable.

In terms of learning difficulties, Alfiani and Fazila (2025) found that before intervention, Grade V students struggled to independently classify substances because they were accustomed to receiving information passively. The abstract nature of acid-base concepts makes it difficult for students to connect theory with real-world experience. Furthermore, Budiwati et al. (2023) found that Grade IV IPAS textbooks for the Merdeka Curriculum still contained conceptual presentations with the potential to generate misconceptions, making instructional materials themselves a systemic vector for the spread of misconceptions.

Contributing Factors

At least four interacting factors contribute to the low level of acid-base conceptual understanding at the elementary level. First, Piaget's cognitive developmental framework, which places students aged 7–12 in the concrete operational stage, means they require direct experience with real objects rather than verbal-abstract explanations (Wedyawati & Lisa, 2021). Second, inadequate teacher content competency, as demonstrated by Hasnawati et al. (2022), is the most determinative external factor. Third, the dominance of lecture-based and rote-learning methods, which do not allow students to actively construct understanding, has been criticised by Khofifah et al. (2024). Fourth, the questionable accuracy of teaching materials (Budiwati et al., 2023) and the minimal use of visual learning media to bridge abstract concepts with students' lived experience (Jannah, 2020) further compound the problem.

Improvement Efforts

Various interventions have proven effective at the elementary level. Guided inquiry learning (Margunayasa et al., 2021) significantly reduced elementary students' misconceptions because the inquiry process compels the active reconstruction of understanding. The use of local natural materials, such as turmeric litmus paper (Ananda et al., 2024), not only improved conceptual understanding but also increased learning motivation by connecting concepts to students' everyday contexts. Problem-Based Learning (PBL) assisted by concrete media (Anggraini et al., 2024; Listya et al., 2024) also significantly improved conceptual understanding and reduced misconceptions. Technology-based media such as augmented reality (Syam et al., 2025; Musyadi et al., 2025) and interactive multimedia (Jannah, 2020) open new possibilities for visualising chemical processes that cannot be observed with the naked eye. Additionally, the use of diagnostic instruments such as the two-tier test (Qatrunnada et al., 2025) has proven capable of distinguishing between students who do not know, those who guess correctly, and those who genuinely understand a concept, enabling precisely targeted remediation.

Secondary Chemistry Education (SMP/SMA)

At the secondary education level, acid-base material is formally introduced as a chemistry topic requiring the simultaneous mastery of macroscopic, submicroscopic, and symbolic representations. This complexity makes acid-base one of the topics with the highest rates of misconception and difficulty in the SMP and SMA chemistry curriculum.

Level of Conceptual Understanding

The profile of acid-base conceptual understanding at the SMP/SMA level is generally in the low to moderate category, with a significant gap between rote recall ability and meaningful conceptual understanding. Laliyo et al. (2023) found a mean misconception rate of 64.44% across ten acid-base sub-concepts tested, with the amphoteric property of water reaching 85.31% and acid strength based on pH reaching 75.62%. Naz and Mushtaq (2022) revealed that 60% of conceptual items on acid-base material were categorised as difficult by Pakistani SMA students, encompassing understanding of pH, neutralisation, acid-base strength, and the use of indicators. These cross-national findings indicate that difficulties in acid-base conceptual understanding are not a local phenomenon but a global challenge in secondary chemistry education. Rumape et al. (2024) specifically identified acid-base titration which integrates conceptual, mathematical, and procedural understanding as the most difficult sub-topic and the most susceptible to misconceptions among Grade XI students.

Forms of Misconceptions and Difficulties

Misconceptions at the SMP/SMA level are characterised by greater complexity than at the elementary level, spanning all three levels of chemical representation simultaneously. Nugraha et al. (2026) identified misconceptions at three levels: (a) macroscopic level errors in identifying solution properties through indicators; (b) submicroscopic level failure to visualise the processes of ionisation and proton transfer; and (c) symbolic level difficulty writing balanced acid-base reaction equations. Zuhroti et al. (2018) confirmed that understanding is strongest at the macroscopic level (directly observable phenomena) but very weak at the submicroscopic and symbolic levels. Students may observe changes in litmus indicator colour but cannot explain why such changes occur at the particle level an inability that Redhana et al. (2020) identified as a mismatch between students' mental models and actual scientific concepts.

Misconceptions originating from students' own personal thinking are the most pedagogically significant finding. Febriana et al. (2025) used a five-tier diagnostic test instrument to reveal that 73.44% of misconception causes stemmed from students' personal beliefs, followed by inaccurate textbook sources (13.65%) and teacher influence (12.5%). This finding has significant implications: effective remediation strategies must explicitly target the reconstruction of students' personal beliefs, rather than merely re-delivering correct information.

Contributing Factors

The dominance of rote-learning and teacher-centred instructional methods is the strongest external factor impeding the formation of meaningful conceptual understanding at the SMP/SMA level. Nugraha et al. (2025) explicitly found, based on teacher interviews, that students' misconceptions are closely related to the absence of opportunities for students to actively construct their own understanding. Laliyo et al. (2023) added a frequently overlooked dimension: the use of inaccurate laboratory jargon or terminology by teachers in explaining acid-base concepts is one of the significant causes of persistent misconceptions. Beyond pedagogical factors, the intrinsic nature of the material which demands the simultaneous integration of three levels of chemical representation is an inherent factor that cannot be avoided. Nurani and Suyanta (2024) found that the absence of teaching materials that explicitly integrate multiple representation in an inquiry-based framework constitutes a structural barrier in SMA chemistry learning.

Improvement Efforts

Multiple representation-based instruction that explicitly connects the macroscopic, submicroscopic, and symbolic levels is the most consistently recommended intervention in the literature. Nurani and Suyanta (2024) demonstrated that guided inquiry-based multiple representation teaching materials are effective in improving acid-base conceptual understanding at the SMA level. Guided inquiry whether in the form of student worksheets/LKPD (Kolo et al., 2022) or as the primary instructional model (Rasid et al., 2020; Muchlis, 2022) consistently outperforms conventional instruction in facilitating deep conceptual understanding. Irnananda et al. (2024) demonstrated the importance of integrating science attitude development into the learning process, as students' scientific attitude significantly affects the quality of the conceptual understanding they achieve. Additionally, the use of three-tier and five-tier diagnostic instruments (Rokhim et al., 2023; Febriana et al., 2025) is a fundamental prerequisite for effective remediation, as it enables teachers to specifically identify the root causes of misconceptions before designing instructional interventions.

Higher Chemistry Learning (University Level)

At the university level, conceptual understanding of acids and bases constitutes a foundational competency that students must master in order to comprehend advanced chemistry topics such as salt hydrolysis, buffer solutions, and reaction kinetics. Nevertheless, the literature review indicates that misconceptions from prior educational levels do not automatically disappear when students enter higher education rather, they are carried forward, modified, and in some cases reinforced when students encounter more complex concepts.

Level of Conceptual Understanding

Research at the university level remains relatively limited compared to secondary education, yet the available findings are concerning. Izza et al. (2021) found significant misconceptions among university students regarding the sub-concepts of pH and acid strength, indicating that even chemistry students' understanding often remains at a surface level without a comprehensive grasp of the underlying chemical logic. Irawati (2019) confirmed that weak acid-base conceptual understanding at the SMA level has a direct and measurable impact on students' ability to understand salt hydrolysis at the subsequent educational level an empirical demonstration of the hierarchical and cumulative nature of chemistry understanding. These findings align with Fathonah et al. (2024), who concluded through a literature review that low chemistry conceptual understanding is found consistently across all levels of education, including university, with patterns of failure that frequently trace back to foundations not properly established at the secondary level.

Forms of Misconceptions and Difficulties

Misconceptions among university students are generally residual in nature remnants of unidentified and inadequately remediated misconceptions from senior high school. Izza et al. (2021) identified that the most prominent misconceptions among university students occur with regard to the concept of acid-base strength (the distinction between strong and weak acids in the context of dissociation), the calculation of pH in mixed solutions, and the application of acid-base concepts in the context of equilibrium reactions. These difficulties are compounded by the higher cognitive demands of university-level study, where conceptual understanding is required not only at the descriptive level but must also reach the levels of analysis, evaluation, and synthesis. Azizah et al. (2022) empirically demonstrated that the misconception patterns found at the elementary and secondary levels do not fully disappear at the university level; instead, they undergo modifications that can make them more difficult to identify and remediate.

Contributing Factors

At the university level, the factors contributing to low acid-base conceptual understanding have characteristics that differ from those at prior educational levels. First, the accumulation of undetected misconceptions from earlier levels is the primary and most difficult-to-address factor (Azizah et al., 2022; Izza et al., 2021). Second, the dominance of lecture-based instruction at university, which rarely incorporates inquiry activities or conceptual exploration, reinforces rote-learning patterns already established during secondary education (Fathonah et al., 2024). Third, the absence of pre-assessment or misconception diagnosis at the beginning of courses means that lecturers are unaware of the misconception profile that students bring, causing instruction to proceed without directed remediation (Rokhim et al., 2023). Fourth, the gap between the formal representations used in university textbooks which tend to move directly to the symbolic level and students' representational abilities, which remain weak at the submicroscopic level, constitutes a significant cognitive barrier (Soeharto & Csapo, 2021).

Improvement Efforts

The literature review identifies several relevant approaches for improving acid-base conceptual understanding at the university level. Rokhim et al. (2023) recommend the use of a three-tier diagnostic instrument as an entry test at the beginning of courses to map students' misconception profiles before instruction begins. This approach enables lecturers to design instruction that begins with the identification and deconstruction of misconceptions, rather than assuming that students already possess correct conceptual foundations. The integration of multiple representation in course materials demonstrated to be effective at the SMA level by Nurani and Suyanta (2024) also holds considerable potential at the university level to bridge gaps in students' representational abilities. Musyadi et al. (2025) show that augmented reality media, which is consistently effective across educational levels, has the potential to be utilised in university chemistry instruction, particularly for visualising submicroscopic processes that cannot be directly observed. Irawati (2019) affirms that structured and measurable strengthening of acid-base concepts at the SMA level has a direct positive impact on the understanding of advanced topics at the university level, underscoring the importance of curricular continuity between secondary and higher education.

Comparative Analysis Across Educational Levels

Table 2. Comparative Analysis

Comparison Aspect	Elementary	Midle (Secondary)	Higher Education
Level of understanding	Low; concrete-phenomenological	Low–moderate; misconceptions across all three representational levels	Persistent misconceptions carried over from prior educational levels
Dominant misconceptions	Overgeneralisation of acid/base properties from sensory experience	pH, acid-base strength, indicators, amphoteric properties	Advanced concepts: hydrolysis, buffer; residual misconceptions from lower levels
Primary factors	Inaccurate teacher competency; abstract material; passive methods	Dominance of rote learning; absence of multiple representation; quality of teaching materials	Transferability of misconceptions from basic levels; lecture-based methods
Common methods	CAR, experiment, case study	Three-tier/five-tier test, quasi-experiment	Literature review, PRISMA, psychometric analysis, correlational
Effective interventions	Inquiry + natural materials; concrete visual media	Multiple representation; guided inquiry; AR media	Structured remediation; multi-tier diagnostic instruments; PjBL
Research gap	Diagnostic instruments for SD still very limited	Integration of MR in formal curriculum; longitudinal SMP–SMA studies	Empirical research at university level still very scarce; cross-cultural validation

Table 2 illustrates a finding that is consistent across all reviewed studies: regardless of educational level, cultural background, or measurement method, students' acid-base conceptual understanding falls in the low to moderate category. Cross-national findings (Naz & Mushtaq, 2022; Soeharto & Csapo, 2021) indicate that this problem is global and systemic, not merely a local phenomenon. All studies also agree that student-centred approaches inquiry, PBL, PjBL, and multiple representation-based learning are significantly more effective than conventional instruction in facilitating meaningful understanding. The most striking difference lies in the complexity of misconceptions, which increases with educational level. At the elementary level, misconceptions take the form of simple overgeneralisations from sensory experience. At the SMP/SMA level, misconceptions develop into complex, three-dimensional alternative frameworks. At the university level, misconceptions are residual but hidden beneath apparently adequate procedural ability. The direct implication of these differences is that the design of diagnostic instruments and remediation strategies must also differ at each level: two-tier tests for SD, five-tier tests for SMA, and profiling-based pre-assessments for university.

LEARNING INPUT FACTORS • Abstract nature of chemistry content • Students' prior misconceptions • Teacher content competency • Quality of teaching materials • Dominance of conventional methods	→	**MISCONCEPTIONS & DIFFICULTIES** • Macroscopic level • Submicroscopic level • Symbolic level • Overgeneralisation • Persistent cross-level misconceptions	→	**INTERVENTION STRATEGIES** • Guided inquiry • Problem/Project-Based Learning • Multiple representation • Multi-tier diagnostic instruments • AR media & interactive multimedia
		↓ **MEANINGFUL CONCEPTUAL UNDERSTANDING** • Integration of all three chemical representational levels • Transfer of concepts to new and varied contexts • Measurable and meaningful chemical literacy		

Figure 1. Conceptual Model

Furthermore, the cross-study analysis identifies four significant research gaps. First, the majority of studies are cross-sectional, measuring understanding at a single point in time. Longitudinal research tracking the development of misconceptions from elementary to university level in the same subjects has not yet been conducted, so the mechanisms of misconception persistence and transformation across educational levels remain poorly understood. Second, valid and reliable diagnostic instruments specifically designed for acid-base material at the elementary and university levels are still very limited. Third, empirical research on the implementation of multiple representation-based instruction in university chemistry courses beyond merely conceptual reviews is still very rarely conducted. Fourth, the impact of the Merdeka Curriculum implementation on the quality of acid-base conceptual understanding has not yet been comprehensively investigated, even though this curricular change has fundamentally altered the context of learning (Nurani & Suyanta, 2024; Budiwati et al., 2023). Four future research directions can accordingly be proposed. First, longitudinal cross-level research tracking acid-base misconception development from elementary to university level should be prioritised. Second, the development and validation of standardised diagnostic instruments for acid-base material at the elementary and university levels is an urgent need. Third, research on the implementation of multiple representation within the Merdeka Curriculum context particularly in IPAS at the elementary level and inquiry-based chemistry learning at the SMA level needs to be conducted to produce contextually grounded and applicable models. Fourth, cross-cultural comparative studies on acid-base misconception patterns across developing nations can provide more comprehensive insight into the universal versus contextual factors influencing conceptual understanding.

Conceptual Model: A Framework for Understanding Acids and Bases

Based on the literature synthesis conducted, the following conceptual framework is proposed to explain the relationships among learning input factors, the misconceptions that form, pedagogical intervention strategies, and meaningful conceptual understanding as the ultimate outcome. This model integrates findings from the elementary, secondary, and university levels across educational contexts.

The conceptual model above illustrates that misconceptions and learning difficulties are products of the interaction among learning input factors. Misconceptions manifest simultaneously across all three levels of chemical representation and are reinforced by students' overgeneralisation from informal experiences. Effective intervention strategies work by reconstructing students' representations across all three levels in an integrated manner through inquiry, PBL/PjBL, multiple representation, and the use of diagnostic instruments. The ultimate output is meaningful conceptual understanding: the ability to integrate all three representational levels, transfer concepts to new contexts, and attain measurable chemical literacy.

CONCLUSION

This study concludes that students' understanding of acid-base concepts remains low to moderate, characterised by the dominance of rote memorisation over meaningful understanding. This low level of understanding is primarily attributable to the abstract nature of acid-base material, in which students frequently struggle to integrate macroscopic, microscopic, and symbolic representations. The literature analysis identifies sub-concepts such as determining acid-base strength and calculating the degree of acidity (pH) as the most difficult to understand and the most susceptible to misconceptions. This condition is influenced by the interaction of various factors from internal to external including the insufficient visualisation of molecular processes in the instructional models employed by teachers. A transformation in science learning strategies is therefore required, with greater emphasis on strengthening molecular-level understanding, in order to improve the quality of students' conceptual understanding and chemistry literacy in the future.

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