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The Relationship Between Collaborative Skills and Chemistry Learning Achievement

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Abstract: *This study investigates the relationship between students' collaborative skills and their achievement in chemistry learning, particularly on the topic of acid–base concepts. Collaborative ability plays an essential role in supporting effective learning and knowledge construction, especially in cooperative classroom settings. The research involved 255 eleventh-grade students who completed both a collaborative skills questionnaire and a chemistry achievement test. The collaborative skills instrument consisted of 23 items covering 11 dimensions, while the achievement test assessed students' understanding of acid–base concepts. Data were analyzed using Spearman's correlation after confirming normality and identifying a non-linear relationship. The results revealed a positive and significant correlation between collaborative skills and learning achievement ($r = 0.501$; $p < 0.001$), with a determination coefficient of 25.1%. These findings indicate that students with stronger collaborative skills tend to achieve higher levels of conceptual mastery in chemistry. Overall, the study emphasizes the importance of developing collaboration competencies to enhance academic performance in science learning.*

Keywords: *collaborative skills; learning achievement; multiple choice multiple answer; acid-base concept*

INTRODUCTION

Twenty-first-century education requires students to develop critical, creative, collaborative, and adaptive thinking skills to face global challenges (Sa-Ngiemjit et al., 2025). In chemistry learning, which is recognized as a conceptual discipline, students often encounter difficulties in understanding the interconnections among complex concepts. This condition underscores the importance of mastering 21st-century skills to support a deeper understanding of chemistry concepts (Redhana, 2019). The Partnership for 21st Century Learning categorizes these skills into three groups: information, media, and technology skills; life and career skills; and learning and innovation skills. Among these, collaborative ability is considered particularly important in the context of chemistry education (P21, 2019). Similarly, the Indonesian Ministry of Primary and Secondary Education has emphasized that one of the key dimensions of student graduate profiles is collaborative competence (Kemendikdasmen, 2025).

Previous research consistently highlights the vital role of collaboration in enhancing student achievement. Effective collaboration enables learners to work together, share ideas, and strengthen their conceptual understanding (Lapitan et al., 2023). In the context of thermochemistry, Wulandari and Rohaeti (2024) emphasized that collaborative learning facilitates students' comprehension of macroscopic, microscopic, and symbolic representations through discussion and collective exploration, which helps them address misconceptions and build a more integrated understanding of chemical concepts. Beyond conceptual mastery, collaborative learning can also help students connect abstract chemical concepts with real-life contexts and engage more meaningfully in the learning process (Liao et al., 2019). Moreover, collaborative practices enhance social interaction and contribute to improved academic outcomes at the group level (Andrews et al., 2020). These findings affirm that collaboration contributes significantly to both the quality of the learning process and the learning achievement attained by students.

However, most previous studies have examined collaboration primarily as a learning model rather than as an individual skill related to academic performance. Research that specifically analyzes the relationship between collaborative ability and chemistry learning achievement remains limited, particularly in complex conceptual topics such as acid–base concepts. Acid–base concepts are fundamental in chemistry, yet numerous studies indicate that students continue to experience misconceptions. These misunderstandings appear in various aspects, including neutralization, the ionization of strong and weak acids and bases, reactions of acids with metals, and the electrical conductivity of solutions. Such misconceptions reveal students' difficulties in connecting submicroscopic and symbolic representations of chemical concepts, emphasizing the need not only for conceptual understanding but also for collaborative skills that support discussion, idea sharing, and clarification of reasoning. This underscores a gap between the demands of 21st-century learning and the availability of empirical research (Nahadi et al., 2023).

Therefore, this study explicitly aims to determine the correlation between students' collaborative abilities and their chemistry learning achievement on acid–base concepts. The novelty of this research lies in its analysis of 21st-century skills, specifically collaboration within the context of chemistry learning, which is expected to provide theoretical contributions to the development of chemistry education literature as well as practical insights for teachers in designing learning strategies that foster collaboration.

LITERATURE REVIEW

Collaborative Skills

Collaborative skills refer to the ability to work together toward shared goals through effective communication, coordination, and contribution from each member (Qureshi et al., 2023). Within the learning context, collaboration enables students to integrate perspectives, exchange explanations, and construct knowledge collectively. Effective collaboration has been shown to enhance academic achievement and improve social interaction, benefiting both individuals and the group as a whole (Andrews et al., 2020; Haataja et al., 2022).

In chemistry learning, collaboration encourages students to reflect on prior conceptions, express ideas through multiple representations, and negotiate shared understanding with peers. This process promotes participation, feedback, and joint decision-making, resulting in more accurate conceptual understanding (Ying & Tiemann, 2024). Beyond strengthening mastery at the macroscopic, microscopic, and symbolic levels, collaboration also develops essential social competencies such as communication, teamwork, and responsibility, key attributes of 21st-century learners (Heeg et al., 2020).

Collaborative skills are interrelated with critical thinking, communication, and self-regulation. Their development should align with the learning content and the students' sociocultural context, and therefore requires authentic, process-oriented assessments (Evans, 2020). In the framework of 21st-century learning, collaboration extends beyond group work to encompass interpersonal and cognitive abilities such as open communication, conflict resolution, and consensus-based decision-making. In chemistry education, these abilities can be fostered through project-based learning, structured discussions, and technology-supported collaboration (Boka et al., 2024). This aligns with the 4C framework, critical thinking, creativity, communication, and collaboration, which underpins 21st-century education.

Empirical findings in chemistry education reinforce these perspectives. Siregar & Simatupang (2020), reported that students taught through problem-based learning on acid–base topics achieved higher levels of engagement and performance compared to conventional methods, demonstrating that active, discussion-oriented learning fosters both understanding and achievement. Similarly, project-based and inquiry-oriented chemistry instruction has been shown to improve collaborative competence and academic performance by involving students in meaningful problem-solving and authentic scientific practices (Simamora, 2022). Collaboration takes place in both face-to-face and online environments, providing opportunities for shared discussion and collective problem-solving. Consequently, it functions not only as a method of learning but also as an educational goal that promotes students' academic and social competence (Boholano, 2017).

A synthesis of international studies by Ha Le, Janssen & Wubbels (2018), Zheng et al. (2023), and Mphahlele (2024) identified six major dimensions of collaborative assessment: social interaction, active participation, group regulation, communication, joint decision-making, and the quality of collaborative products. These studies emphasize that assessment should capture both outcomes and the underlying social–cognitive processes, providing a comprehensive framework for developing authentic instruments to evaluate collaboration (Le et al., 2018; Mphahlele, 2024; Zheng et al., 2023).

Chemistry Learning Achievement

Learning achievement indicates students' level of competence after instruction. It is categorized into cognitive, affective, and psychomotor domains. The cognitive domain includes intellectual abilities such as remembering, understanding, analyzing, and creating, as outlined in Bloom's revised taxonomy. The affective domain relates to attitudes and motivation, while the psychomotor domain involves skills that support learning activities (Suwannatrai, 2022).

This study focuses on the cognitive domain, which can be assessed through tests, discussions, projects, and other learning tasks (Sari & Rahmah, 2019). In chemistry, achievement reflects students' ability to understand concepts, apply knowledge, and solve experiment-based problems (Agustian et al., 2022). Achievement can be improved through instructional models that integrate problem-solving, experimentation, and collaboration. Students who collaborate effectively tend to have higher motivation, engagement, and self-confidence, which enhance learning outcomes (Warsah et al., 2021). Interactive and contextual chemistry learning fosters deeper understanding and better achievement (Sinchai et al., 2023). However, many students still struggle to grasp acid–base concepts and to link abstract ideas (Linda et al., 2024). This highlights the need for approaches that promote both conceptual mastery and collaborative skill development.

Acid–Base Concepts as a Context

Acid–base theories—Arrhenius, Brønsted–Lowry, and Lewis—offer different criteria for identifying acids and bases. The strength of acids and bases is determined by their dissociation constants (Ka and Kb), with larger values indicating stronger properties (Zumdahl & Zumdahl, 2010). Indicators, such as litmus, change color within specific pH ranges, while the pH scale provides a simple measure of acidity and alkalinity (Oxtoby et al., 2016; McMurry & Fay, 2012).

Acid–base concepts are ideal for exploring the link between collaboration and achievement because of their conceptual complexity and the need for teamwork in laboratory experiments. Rizal & Fitriza (2021) emphasize that successful learning of these concepts depends not only on understanding but also on students' ability to collaborate, discuss, and adapt during experiments. Therefore, this study employs acid–base concepts as a context to examine how collaboration influences students' chemistry learning achievement.

METHODS

Research Design

This study employed a quantitative approach with a correlational survey design. The purpose was to analyze the relationship between students' collaborative skills and their chemistry learning achievement on acid–base concepts. The research was conducted in three general phases: preparation (instrument development and preliminary observation), implementation (data collection), and completion (data analysis and reporting).

Participants

The participants consisted of 255 eleventh-grade students from four senior high schools. Schools were selected using purposive sampling, based on the implementation of instructional practices that promote collaboration. From each school, students were then chosen through simple random sampling (Cohen et al., 2007)

Instruments

Two research instruments were used in this study, namely a collaborative skills questionnaire and a chemistry learning achievement test. The collaborative skills questionnaire was designed as a self-assessment instrument using a five-point Likert scale. It was developed based on 21st-century skills and collaborative learning frameworks to measure students' ability to communicate, coordinate, and contribute effectively during group activities (Hinyard et al., 2019). Meanwhile, the chemistry learning achievement test adopted a Multiple Correct Multiple Answer (MCMA) format to assess students' understanding of acid–base concepts, as this structure allows multiple correct responses and encourages deeper reasoning rather than mere guessing (Oc & Hassen, 2024).

Both instruments underwent expert validation and reliability testing to ensure quality. The content validity was assessed using the Content Validity Ratio (CVR) and Content Validity Index (CVI) (Lawshe, 1975), while the reliability was measured through Cronbach's Alpha and Inter-Rater Reliability (IRR). All items were found to be valid and reliable, with coefficients exceeding the recommended threshold ($\alpha > 0.80$). In addition, the Item Response Theory (IRT) approach was employed to analyze item difficulty, discrimination, and model fit. The Generalized Partial Credit Model (GPCM) was applied for the MCMA achievement test, while the Rating Scale Model (RSM) was used for the questionnaire, both selected according to the data characteristics (Andrich, 1978; Muraki, 1992) . Misfitting items were removed based on statistical fit criteria, resulting in 17 valid test items and 23 valid questionnaire items used for data collection.

Data Analysis

Data analysis was conducted using SPSS version 27. The analytical procedures included descriptive statistics, assumption testing (normality, linearity), and Spearman's rank correlation to test the relationship between collaborative skills and chemistry learning achievement. The use of Spearman's correlation was based on the result of the linearity test, which indicated that the relationship between variables was not entirely linear.

Research Hypothesis

Based on the theoretical framework and prior studies, the research hypothesis is formulated as follows:

H_0: There is no significant correlation between students' collaborative skills and their chemistry learning achievement.

H_1: There is a positive and significant correlation between students' collaborative skills and their chemistry learning achievement.

RESULT AND DISCUSSION

The chemistry learning achievement test consisted of 17 Multiple Choice Multiple Answer (MCMA) items covering key acid–base topics, including acid–base properties, theoretical models (Arrhenius, Brønsted–Lowry, and Lewis), ionization constants, strength, and pH-related calculations (Zumdahl & Zumdahl, 2010). The distribution of items according to each concept is presented as follows:

Table 1. Distribution of Learning Achievement Test Items by Concept

Concept / Topic	Number of Items
Role of acid–base solutions in daily life	2
Properties of acid–base solutions	1
Arrhenius theory	2
Brønsted–Lowry theory	2
Lewis theory	2
Acid and base ionization constants (Ka and Kb)	1
Acid–base strength	2
Solution identification	1
pH prediction	2
pH calculation	2

The results of the learning achievement test and the histogram graph are presented as follows:

Table 2. Chemistry Learning Achievement Data

Data	Result
Number of Respondents	255
Lowest Score	9
Highest Score	49
Maximum Score	51
Mean Score	37.78
Standard Deviation	7.77
Average Achievement	74.1 %

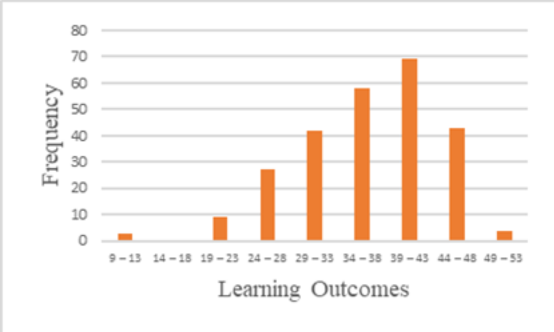

Figure 1. Histogram of Chemistry Learning Achievement

Results from the learning achievement test showed a wide distribution of scores, ranging from 9 to 49 out of a maximum of 51. The mean score of 37.78 (SD = 7.77) corresponded to an average achievement of 74.1%, indicating that students generally demonstrated a good understanding of acid–base concepts. The score distribution (Figure 1) revealed that most students fell within the medium-to-high range, suggesting adequate conceptual mastery but also notable variation across individuals.

In addition to the achievement test, students' collaborative skills were assessed using a self-report questionnaire consisting of 23 statements. The distribution of items according to each concept is presented as follows:

Table 3. Distribution of Collaborative Skills Questionnaire imensions

Dimensions	Number of Items
Contribution	2
Team support	1
Team dynamics	2
Interaction with others	3

Role flexibility	1
Participation	2
Quality of work	3
Time management	2
Preparation,	2
Reflection	1
Team learning	4

The collaborative skills data are presented as follows:

Table 4. Collaborative Skills Data

Data	Result
Number of Respondents	255
Lowest Score	23
Highest Score	114
Mean Score	82,34
Standard Deviation	14,30
Average Achievement	71,6%

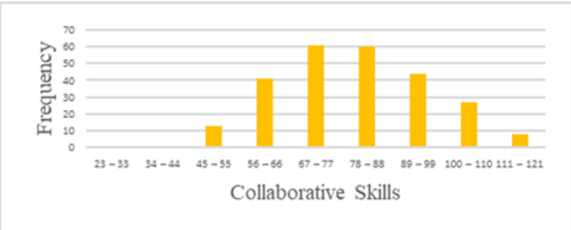

Figure 2. Histogram Collaborative Skills

The results of the collaborative skills questionnaire showed that students' scores ranged from 23 to 114, with a mean of 82.34 and a standard deviation of 14.30, equivalent to 71.6% of the maximum possible score. The histogram illustrates that most students scored within the medium-to-high range, indicating that their collaborative competence was generally well developed. This suggests that students were able to contribute actively, communicate effectively, and coordinate with peers during group activities. Nevertheless, the distribution also shows some variation across individuals, reflecting differences in students' consistency and engagement within collaborative tasks.

Following the findings that both chemistry learning achievement and collaborative skills were categorized as good, with scores concentrated in the medium-to-high range, assumption tests were conducted to verify data suitability for inferential analysis. The normality test using the One-Sample Kolmogorov–Smirnov Test yielded a significance value of 0.074 ($p > 0.05$), indicating that the data were normally distributed. However, the linearity test showed a Deviation from Linearity significance of 0.019 ($p < 0.05$), suggesting that the relationship between the two variables was not fully linear. Based on these results, the nonparametric Spearman's rank correlation test was used for hypothesis testing.

Table 5. Results of Spearman's Rank Correlation Test

Spearman'srho	N	255
	Correlation Coefficient	0,501
	Sig. (2-tailed)	<,001

The Spearman's correlation analysis revealed a significance value of < 0.001 ($p < 0.05$), indicating a statistically significant and positive relationship between students' collaborative skills and their chemistry learning achievement. The correlation coefficient of 0.501 suggests a moderately strong association (Dancey & Reidy, 2004), implying that students with higher collaborative skills tend to achieve better learning outcomes. The coefficient of determination (r^2 = 25.1%) further indicates that collaboration contributes meaningfully to academic performance, although it is not the sole influencing factor.

Collaborative engagement enables students to expand their understanding through shared learning experiences, idea exchange, and constructive interaction, all of which strengthen comprehension and support the achievement of common academic goals (Hasan et al., 2023; Sokhanvar et al., 2021). Collaboration, however, does not develop in isolation; it is inherently linked to the cultivation of other essential competencies. Among these, communication, adaptability, critical thinking, and problem-solving serve as core components that help students work productively with others and navigate complex learning situations.

Communication refers to the ability to convey and interpret messages effectively through speaking, writing, active listening, and persuasive interaction. These skills are essential for building mutual understanding, fostering cooperation, and ensuring that collaborative processes are carried out productively (Karaca-Atik et al., 2023). Alongside communication, adaptability plays a crucial role in supporting collaboration. It represents the capacity to adjust one's thoughts and behaviors in response to new or uncertain learning situations. In this regard, adaptability enables students to embrace diverse perspectives and remain engaged in dynamic environments, forming a solid foundation for achieving shared goals (Negru-Subtirica & Pop, 2016).

Critical thinking and problem-solving also reinforce collaboration in chemistry learning. Critical thinking allows students to analyze information logically, evaluate evidence, and make reasoned judgments when confronting complex problems, which contributes to a deeper and more meaningful understanding (Kotsiou et al., 2022). Meanwhile, problem-solving involves identifying challenges, generating strategies, and applying knowledge to real-world contexts through logical reasoning. As key 21st-century competencies, these skills not only support academic achievement but also prepare students to respond effectively to the evolving demands of modern education (Yalçın & Erden, 2021).

Recent studies in chemistry education also confirm the growing importance of collaboration in improving learning outcomes. Auliah & Cahyani (2024), found that research trends from 2019–2024 have increasingly focused on collaborative and inquiry-based learning, reflecting global efforts to integrate 21st-century skills into chemistry instruction. Their results align with the findings of this study, which demonstrate that collaboration significantly contributes to students' conceptual understanding and academic performance. Likewise, Adlar Fadli et al., (2025), reported that video-assisted Problem-Based Learning and Discovery Learning enhanced students' mastery of acid–base concepts, emphasizing that non-cognitive skills such as motivation and collaboration play a vital role in improving achievement. Furthermore, Elisabeth Frenklin Pangaribuan & Ani Sutiani (2025), showed that problem-based learning supported by virtual laboratory media leads to higher chemistry achievement compared to traditional or game-based approaches. These consistent findings indicate that interactive, inquiry-oriented, and collaborative learning environments effectively foster both engagement and understanding, key dimensions of successful chemistry learning.

In summary, communication, adaptability, critical thinking, and problem-solving collectively strengthen students' collaborative abilities, leading to meaningful interaction and improved learning outcomes. In chemistry education, such competencies contribute to achievement by enhancing students' capacity to apply knowledge, connect abstract concepts with real-world contexts, and engage critically with problems. Individual, social, and institutional factors also shape student achievement. Cognitive ability, motivation, and emotional readiness provide the foundation for learning (Ishida & Sekiyama, 2024), while socioeconomic background influences access to resources and learning opportunities (Kocak et al., 2021). Additionally, teacher quality, classroom climate, and learning materials significantly affect academic success (Suleiman et al., 2024).

Therefore, improving chemistry learning achievement requires instructional approaches that promote active engagement and collaboration, such as problem-based or project-based learning. The use of diverse learning resources—including visual aids, digital tools, and formative assessments with timely feedback—can further help students construct and refine their understanding.

Strengthening collaboration and its related competencies not only deepens conceptual mastery but also enhances students' ability to learn meaningfully and achieve higher academic performance.

CONCLUSION

This study found a positive and significant correlation between students' collaborative skills and their chemistry learning achievement on acid–base concepts. Students with stronger collaborative abilities tended to achieve higher learning outcomes, with collaboration contributing approximately 25.1% to overall achievement. These findings confirm that collaboration plays a key role in supporting students' conceptual understanding and cognitive performance in chemistry learning.

Beyond these findings, the results carry important implications for educational practice and policy. Teachers should design classroom activities that actively foster collaboration, such as group experiments, project-based learning, and peer discussions, to strengthen both academic and interpersonal competencies. Meanwhile, policymakers and curriculum developers are encouraged to emphasize collaborative skills as a core component of science education standards and assessments, ensuring that 21st-century competencies are systematically integrated into teaching and learning processes.

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