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The Analysis of the Influence of Social Interaction on Students' Chemistry Learning Outcomes in Buffer Solution Topics at Secondary School

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ABSTRACT

This study aims to analyze the influence of social interaction on students' chemistry learning outcomes in buffer solution topics at the secondary school level. The research employed a quantitative approach with a quasi-experimental design conducted among Grade XI science students at SMA Hang Tuah Makassar, involving a total sample of 67 participants. Data on social interaction were collected using a Likert-scale questionnaire, while learning outcomes were measured through a multiple-choice test. The data were analyzed using descriptive and inferential statistics, including ANOVA and Tukey post hoc tests. The results revealed that social interaction has a statistically significant effect on students' chemistry learning outcomes ($p < 0.05$). Students with high levels of social interaction achieved higher learning outcomes compared to those with moderate and low levels. Furthermore, all categories of social interaction showed significant differences from one another. These findings indicate that social interaction is a key predictor in improving chemistry learning outcomes, particularly in complex topics such as buffer solutions. Therefore, instructional strategies that promote active social interaction among students can serve as an effective approach to enhance the quality of chemistry learning.

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INTRODUCTION

Science education, particularly chemistry, plays a strategic role in fostering students' critical thinking, analytical abilities, and problem-solving skills. However, in practice, chemistry learning continues to face numerous challenges, especially those related to the complexity of abstract and multidimensional concepts, such as buffer solutions, which require simultaneous understanding at macroscopic, submicroscopic, and symbolic levels. These demands frequently lead to learning difficulties and misconceptions among students (Sholikhah & Priyasmika, 2025). The high level of misconceptions, reaching approximately 36.5%, indicates that a considerable proportion of students have not yet achieved a comprehensive and in-depth understanding of the concepts, which directly impacts their chemistry learning outcomes (Sholikhah & Priyasmika, 2025). In addition, low learning outcomes are often associated with the continued use of conventional teaching methods that insufficiently engage students in active learning processes, resulting in passive learning behaviors where students merely receive information without constructing their own understanding (Yusuf, 2014). This condition suggests that teacher-centered approaches focused solely on knowledge transmission are no longer adequate to address the challenges of modern chemistry education, thus necessitating instructional approaches that facilitate active and meaningful knowledge construction through direct student engagement.

From the perspective of contemporary learning theories, constructivism serves as a fundamental framework emphasizing that knowledge is not passively transferred from teachers to students but is actively constructed through experience, where learners function as active agents who build understanding by reflecting on their learning experiences (Priyamvada, 2018). Furthermore, social constructivism highlights that knowledge construction is inherently linked to social interaction, as understanding emerges through negotiation of meaning facilitated by dialogue, collaboration, and exchange of ideas among individuals within a learning environment (Lenkauskaite et al., 2020). In this context, social interaction functions not only as a communication medium but also as a central epistemological mechanism in knowledge formation, where students develop understanding through discussion, argumentation, and collective reflection. Therefore, the quality of social interaction in the classroom becomes a crucial factor that can significantly influence students' learning outcomes.

Social interaction in learning environments can be implemented through various instructional approaches, particularly collaborative and cooperative learning, which enable students to work together in small groups to achieve shared learning goals, thereby promoting idea exchange, discussion, and deeper conceptual elaboration. Meta-analytic studies have demonstrated that collaborative learning exerts a significant positive effect on improving learning outcomes compared to traditional instructional methods (Kaldırım & Tavşanlı, 2018; Eslit, 2023). In the context of chemistry education, the implementation of cooperative learning has been shown to be more effective in enhancing students' academic achievement than conventional methods, yielding substantial improvements in learning outcomes (Sibomana et al., 2021). Additionally, cooperative learning facilitates conceptual understanding through active interaction among students, allowing for the exchange of perspectives and collective clarification of concepts (Mubarok et al., 2025). These findings indicate that structured social interaction within the learning process contributes significantly to improving both the quality of instruction and students' academic performance.

Moreover, social interaction not only influences cognitive achievement but also contributes to the development of students' cognitive and metacognitive abilities. Through interaction, students engage in processes of elaboration, clarification, and reflection, which lead to deeper conceptual understanding. Peer interaction, in particular, represents an effective form of social engagement, as it allows students to exchange perspectives and co-construct knowledge through group discussions. Research indicates that interaction among students can facilitate conceptual change through cognitive and social conflict arising during discussions, ultimately promoting more scientifically accurate understanding (Michelsen & Groß, 2024). In addition, social interaction supports the development of higher-order thinking skills, such as analysis, synthesis, and evaluation, which are essential in mastering complex and abstract chemistry concepts.

From a cognitive development perspective, social interaction plays a central role in the learning process, as explained in Vygotsky's theory, which posits that learning occurs through social interaction within the zone of proximal development, where students can achieve higher levels of understanding with the assistance of more capable peers or instructors. Interaction with peers enables students to support one another in understanding difficult concepts through scaffolding processes that enhance their cognitive development (Forman, 1989). This perspective underscores that learning is not merely an individual activity but also a social process in which knowledge is constructed through interaction and collaboration. Consequently, social interaction becomes a key determinant in the development of students' cognitive abilities, which directly influences their learning outcomes.

In the context of science education, numerous studies have demonstrated that social interaction significantly affects students' academic achievement, both through peer interaction and student–teacher interaction. Empirical evidence indicates that peer–peer interaction and student–lecturer interaction significantly influence students' academic performance in science learning (Mafugu, 2021). Furthermore, forms of social interaction such as peer assessment and self-assessment have been found to be strongly associated with academic achievement, as students who actively participate in evaluative processes tend to develop better conceptual understanding (Nurismawati et al., 2025). These findings suggest that social interaction functions not only as a learning process but also as an important predictor of students' learning outcomes.

Despite extensive research highlighting the importance of social interaction in education, most studies have primarily focused on its implementation within specific instructional models, such as cooperative and collaborative learning, rather than examining social interaction as an independent variable. Moreover, studies that specifically investigate the role of social interaction as a predictor of chemistry learning outcomes, particularly in buffer solution topics, remain limited, even though this topic is characterized by high conceptual complexity and susceptibility to misconceptions. This indicates a clear research gap that needs to be addressed by examining social interaction as a distinct independent variable influencing learning outcomes, rather than merely as a component embedded within instructional models.

Based on the aforementioned considerations, this study aims to analyze the influence of social interaction on students' chemistry learning outcomes in buffer solution topics at the secondary school level, positioning social interaction as the primary predictor variable. The novelty of this study lies in its explicit focus on social interaction as an independent variable within the context of complex chemistry learning, as well as its integration with buffer solution material, which is known for its high level of misconceptions. Therefore, this study is expected to contribute theoretically to the development of social constructivist perspectives and practically to assist teachers in designing more effective interaction-based learning strategies. Accordingly, the research question guiding this study is: Does social interaction significantly influence students' chemistry learning outcomes in buffer solution topics at the secondary school level?

THEORETICAL REVIEW

Constructivist theory posits that learners actively construct knowledge through experience and interaction with their learning environment, positioning students as central agents in the learning process who generate meaning from acquired information (Priyamvada, 2018). Knowledge, from this perspective, is not static but evolves through cognitive adaptation, integrating new experiences with prior understanding. In the context of chemistry education, students develop conceptual understanding through exploration, reflection, and discussion, making learning more meaningful and profound. Consequently, constructivism provides a strong conceptual foundation for emphasizing active student engagement in learning processes.

Social constructivism further elaborates that social interaction serves as the primary mechanism in knowledge construction, where individuals build understanding through communication, collaboration, and negotiation of meaning within a social context (Lenkauskaite et al., 2020). Learning, therefore, is not solely an individual activity but also a collective process involving peers and teachers. Through interaction, students gain diverse perspectives, clarify misconceptions, and enhance critical thinking skills. Thus, this perspective highlights that the quality of social interaction directly influences the quality of learning outcomes.

The theory of social interaction in learning emphasizes that communication and collaboration among students significantly affect the learning process. Social interaction involves exchanging information, providing feedback, and collaboratively solving problems within group settings. Students who actively engage in such interactions tend to achieve better conceptual understanding compared to passive learners (Mafugu, 2021). Moreover, social interaction supports the simultaneous development of social and cognitive skills, thereby enhancing the effectiveness of the learning process.

Vygotsky's cognitive development theory reinforces this view by explaining that learning occurs through social interaction within the zone of proximal development, where students can reach higher levels of understanding with the support of more capable individuals, such as teachers or peers (Forman, 1989). This process involves scaffolding, in which temporary assistance is provided to facilitate students' comprehension of complex concepts. In chemistry learning, peer interaction enables students to collaboratively solve problems and grasp abstract concepts more effectively, underscoring the critical role of social interaction in cognitive development.

Cooperative learning theory highlights that structured group collaboration can significantly improve students' learning outcomes by promoting positive interdependence, individual accountability, and intensive face-to-face interaction (Khan et al., 2020). Students engaged in cooperative learning environments have greater opportunities to discuss, share ideas, and support one another in understanding academic content. Empirical evidence indicates that cooperative learning is more effective than traditional instructional methods in improving chemistry learning outcomes (Sibomana et al., 2021), thereby reinforcing the importance of social interaction in educational settings.

Similarly, collaborative learning theory asserts that knowledge is constructed through dialogue and shared experiences among learners (Dahiru, 2014). This approach facilitates deeper understanding as students actively participate in exchanging ideas and discussing complex concepts. In chemistry education, collaborative learning is particularly effective in addressing abstract topics, such as buffer solutions, by reducing misconceptions and enhancing conceptual clarity.

Conceptual change theory further explains that meaningful learning occurs when students revise their prior understanding through cognitive conflict arising from social interaction. When students encounter differing viewpoints during peer discussions, they experience conceptual conflict that encourages them to reconstruct their understanding toward more scientifically accurate concepts (Michelsen & Groß, 2024). This process highlights the essential role of social interaction in correcting misconceptions and fostering conceptual development.

Finally, learning outcome theory suggests that students' academic achievement is influenced by multiple factors, including the quality of social interaction during the learning process. Learning outcomes reflect students' mastery of subject matter, typically measured through assessments. Students who actively participate in social interaction tend to achieve better outcomes, as they engage in deeper learning through discussion and collaboration (Nurismawati et al., 2025). In chemistry education, learning success is not solely determined by individual ability but also by the quality of interaction within the learning environment.

In summary, the theoretical perspectives discussed above consistently demonstrate that social interaction plays a crucial role in the learning process and significantly influences learning outcomes. Social interaction functions not only as a means of communication but also as a fundamental mechanism for knowledge construction and cognitive development. Therefore, this study positions social interaction as the primary variable influencing chemistry learning outcomes, particularly in complex topics such as buffer solutions.

METHODOLOGY

This study employed a quantitative approach with a quasi-experimental design structured within a comparative and associative framework to examine the influence of social interaction on students' chemistry learning outcomes in buffer solution topics. This approach was selected as it enables the objective measurement of relationships and causal tendencies between variables, as well as the testing of significant differences in learning outcomes based on varying levels of students' social interaction. Although two instructional models, namely discovery learning and direct instruction, were implemented during the learning process, the conceptual focus of this study remained on social interaction as the primary independent variable influencing learning outcomes. Accordingly, the research design emphasized the categorization of students based on their levels of social interaction (high, moderate, and low), followed by a comparative analysis of chemistry learning outcomes across these categories.

The study was conducted in Grade XI science classes at a secondary school during the second semester of the 2016/2017 academic year. The population consisted of all Grade XI science students, comprising two classes, both of which were selected as the research sample using a total sampling technique. The total number of participants was 67 students, with 34 students in the first class and 33 students in the second class. The classes were assigned randomly without considering initial characteristics, ensuring that each student had an equal opportunity to be included in any instructional group. However, within the context of this study, the primary analytical emphasis was not on differences between instructional models, but rather on variations in students' levels of social interaction across both classes.

The research instruments consisted of both non-test and test instruments. The non-test instrument was a social interaction questionnaire developed using a five-point Likert scale, including the response categories Always (AL), Often (OF), Sometimes (ST), Rarely (RA), and Never (NV). The questionnaire comprised 30 items representing indicators of social interaction in learning, such as peer communication, group collaboration, active participation in discussions, and the ability to exchange ideas. Scoring was assigned based on item polarity, with positive statements scored from 5 to 1 and negative statements scored inversely. The total scores obtained were subsequently used to classify students into high, moderate, and low social interaction categories using the ideal mean (Mi) and ideal standard deviation (Sdi) approach.

Table 1. Classification Criteria of Social Interaction Levels

Category	Criteria
Low	Score < (Mi – 1.5 Sdi)
Moderate	(Mi – 1.5 Sdi) ≤ Score < (Mi + 1.5 Sdi)

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High	Score ≥ (Mi + 1.5 Sdi)

The test instrument was designed to measure students' cognitive learning outcomes in buffer solution topics. It consisted of 20 multiple-choice items, each with five answer options (A, B, C, D, and E). Each correct answer was assigned a score of 1, while incorrect answers were scored 0. The test content covered fundamental concepts of buffer solutions, pH calculations, and the application of concepts in real-life contexts. Prior to implementation, all research instruments underwent a validation process by two experts to ensure content validity, construct validity, and linguistic clarity, thereby guaranteeing that the instruments accurately measured the intended variables.

The research procedure was carried out in three stages: preparation, implementation, and data analysis. During the preparation stage, preliminary observations were conducted to identify the existing conditions of chemistry learning, followed by the development of instructional materials and research instruments. In the implementation stage, the learning process was conducted over four meetings, each lasting 2 × 45 minutes. Upon completion of the instructional sessions, students were administered the social interaction questionnaire to assess their level of interaction during learning, followed by the administration of the learning outcomes test to measure their understanding of buffer solution concepts. The data obtained at this stage reflected the relationship between students' levels of social interaction and their corresponding learning outcomes.

Data collection techniques in this study involved both test and non-test methods. The non-test method was used to collect data on social interaction through the questionnaire, while the test method was employed to obtain data on students' chemistry learning outcomes. The collected data were analyzed using both descriptive and inferential statistical methods. Descriptive analysis was utilized to present the distribution of data, including mean scores, standard deviations, maximum and minimum values for each social interaction category, providing an overview of trends in learning outcomes based on interaction levels.

Prior to hypothesis testing, prerequisite analyses were conducted, including tests of normality and homogeneity. Normality was assessed using the One-Sample Kolmogorov–Smirnov test with the assistance of SPSS version 20 for Windows to determine whether the data were normally distributed. The criterion for normality was a significance value (sig.) greater than 0.05. Homogeneity testing was conducted to examine whether the variance across social interaction groups was homogeneous, with a significance value greater than 0.05 indicating homogeneity. These prerequisite tests were essential to ensure that the assumptions underlying inferential statistical analysis were satisfied.

Hypothesis testing was conducted using analysis of variance (ANOVA) to determine whether significant differences in learning outcomes existed among students with different levels of social interaction. Furthermore, to identify specific differences between interaction groups, a post hoc analysis was performed using the Tukey HSD test. The decision criterion was that if the significance value (p) was less than 0.05, the alternative hypothesis was accepted, indicating that social interaction has a significant effect on students' chemistry learning outcomes. Overall, the methodological design of this study was systematically structured to empirically examine the role of social interaction as a primary predictor of learning outcomes in buffer solution topics.

RESULTS

The findings of this study present empirical evidence regarding the influence of social interaction on students' chemistry learning outcomes in buffer solution topics. The total number of participants involved in this study was 67 students, categorized into three levels of social interaction: high, moderate, and low. The results are systematically presented through descriptive statistics, inferential analysis, and comparative evaluation, following the reporting style commonly adopted in scholarly articles.

Table 2. Descriptive Statistics of Students' Social Interaction

Class	N	Mean	Median	Std. Deviation	Minimum	Maximum
Class 1	34	100	109	25	58	123
Class 2	33	92	103	25	56	122

The results indicate variability in students' social interaction levels across both classes, with Class 1 demonstrating a slightly higher mean score compared to Class 2.

Table 3. Distribution of Students Based on Social Interaction Categories

Social Interaction Category	Class 1	Class 2	Total
High	7	3	10
Moderate	19	19	38
Low	8	11	19
Total	34	33	67

The majority of students fall within the moderate interaction category, followed by low and high categories respectively.

Table 4. Descriptive Statistics of Learning Outcomes by Social Interaction

Category	N	Max Score	Min Score	Mean Score	Std. Deviation
High	10	90	80–85	87	3–4
Moderate	38	85	70–76	77–82	4–6
Low	19	85	55–70	71–78	7–9

Students with high social interaction consistently demonstrate superior learning outcomes compared to other categories.

Table 5. Mean Comparison of Learning Outcomes Based on Social **Interaction**

Social Interaction Level	Mean Score

High	86.90
Moderate	76.60
Low	74.43

A clear trend is observed, where higher levels of social interaction correspond to higher academic achievement.

Table 6. Normality Test Results

Variable	Sig.	Interpretation
Social Interaction (Class 1)	0.060	Normal
Social Interaction (Class 2)	0.052	Normal

Table 7. Homogeneity Test Results

F-value	Sig.	Interpretation
2.137	0.073	Homogeneous

The data meet the assumptions of normality and homogeneity, indicating suitability for parametric testing.

Table 8. ANOVA Results

Source of Variation	F	Sig.
Social Interaction	13.480	0.000
Learning Model	4.492	0.038
Interaction (Model × SI)	0.675	0.513

The ANOVA results reveal that social interaction has a statistically significant effect on students' learning outcomes ($p < 0.05$).

Table 9. Post Hoc Tukey HSD Results

Comparison	Mean Difference	Sig.
High – Moderate	7.3947	0.002
High – Low	13.0526	0.000
Moderate – Low	5.6579	0.003

All pairwise comparisons show statistically significant differences, confirming that each level of social interaction contributes distinctly to variations in learning outcomes.

Table 10. Pattern of Relationship Between Social Interaction and Learning Outcomes

Social Interaction Level	Learning Outcome Trend
High	Highest achievement
Moderate	(moderate) achievement
Low	Lowest achievement

Overall, the findings demonstrate a consistent positive relationship between social interaction and learning outcomes. Students with higher levels of social interaction tend to achieve better academic performance, indicating that social interaction serves as a significant predictor of chemistry learning outcomes in buffer solution topics.

DISCUSSION

The findings of this study demonstrate that social interaction exerts a statistically significant influence on students' chemistry learning outcomes in buffer solution topics, as evidenced by the ANOVA results indicating a significance value of 0.000 ($p < 0.05$). This result confirms the existence of meaningful differences in learning outcomes among students categorized into high, moderate, and low levels of social interaction. Such evidence suggests that social interaction should not be considered merely as a supplementary aspect of the learning process, but rather as a core variable that directly contributes to academic achievement. Within the context of chemistry learning, which requires both conceptual understanding and problem-solving abilities, social interaction functions as a crucial medium for knowledge construction. This finding is consistent with the principles of social constructivism, which emphasize that knowledge is constructed through interactions among individuals within a social environment (Lenkauskaite et al., 2020). Therefore, higher levels of social interaction are associated with greater opportunities for students to achieve optimal learning outcomes.

Descriptively, the results reveal that students categorized as having high social interaction achieved the highest mean scores compared to those in moderate and low categories. This pattern is further reinforced by the post hoc Tukey HSD analysis, which indicates that all pairwise comparisons between interaction categories are statistically significant. These findings support the assumption that social interaction is positively correlated with students' academic achievement. High levels of interaction enable students to actively engage in discussions, exchange ideas, and clarify conceptual misunderstandings, thereby facilitating deeper conceptual comprehension. This is particularly relevant in the context of buffer solution topics, which are characterized by high conceptual complexity and require integrated understanding across multiple representational levels (Sholikhah & Priyasmika, 2025). Consequently, students who actively participate in social interactions are more likely to develop a more robust and scientifically accurate understanding of the subject matter.

Furthermore, the study indicates that students with moderate levels of social interaction also demonstrate better learning outcomes compared to those with low interaction levels. This finding suggests the presence of a gradational effect, where increases in social interaction are followed by corresponding improvements in learning outcomes. Such a pattern highlights that social interaction operates along a continuum rather than as a binary variable. Even at moderate levels, interaction facilitates information exchange and discussion, although not as intensively as in the high category. However, the relatively limited intensity of interaction in this group may constrain the depth of conceptual elaboration, resulting in learning outcomes that are lower than those observed in the high interaction group.

In contrast, students with low levels of social interaction exhibit the lowest learning outcomes among all categories. This condition indicates that limited social engagement may act as a barrier to effective learning. Students in this category tend to be less active in discussions, less involved in group activities, and less confident in expressing ideas or asking questions. As a result, they have fewer opportunities to clarify misconceptions and refine their understanding, leading to less optimal learning outcomes. This finding is aligned with previous research suggesting that low participation in social interaction can hinder knowledge construction processes and negatively impact academic performance (Sibomana et al., 2021).

Additionally, the results reveal that social interaction has a more dominant contribution to learning outcomes compared to other variables examined in this study. Although different instructional models were implemented, the analysis shows no significant interaction effect between instructional models and social interaction (sig = 0.513 > 0.05). This indicates that the influence of social interaction on learning outcomes is independent of the type of instructional model employed. In other words, regardless of whether discovery learning or direct instruction is used, social interaction remains a determining factor in students' academic achievement. This finding implies that enhancing social interaction within the classroom can serve as an effective strategy for improving learning outcomes without being entirely dependent on specific instructional models.

From a theoretical perspective, these findings reinforce the foundational principles of social constructivism, which emphasize the central role of interaction in the learning process. Learning is not merely a process of knowledge transmission from teacher to student, but rather an active and socially mediated process in which students construct understanding through interaction and collaboration. This interpretation is consistent with previous findings indicating that learning environments that actively promote social interaction can significantly enhance students' academic performance (Mafugu, 2021). Therefore, this study contributes to strengthening the theoretical framework regarding the importance of social interaction in science education, particularly in chemistry learning contexts.

From a practical standpoint, the findings suggest that educators should place greater emphasis on fostering social interaction within the learning environment. Instructional strategies should not be limited to content delivery but should also focus on creating opportunities for meaningful interaction among students. This can be achieved through the implementation of group discussions, collaborative tasks, and interactive learning activities that encourage students to exchange ideas and engage actively in the learning process. By enhancing the quality of social interaction, students are more likely to become actively involved in learning and develop a deeper understanding of complex chemistry concepts. Furthermore, improving social interaction can serve as an alternative solution to address low learning outcomes often associated with the abstract and challenging nature of chemistry content.

Despite these contributions, this study is subject to several limitations. First, the research was conducted in a single school with a relatively limited sample size, which may restrict the generalizability of the findings. Second, social interaction was measured using a self-reported questionnaire, which may introduce potential bias due to subjectivity in students' responses. Third, the study focused exclusively on buffer solution material, limiting the extent to which the findings can be generalized to other chemistry topics. Therefore, future research is recommended to involve larger and more diverse samples, employ multiple methods for measuring social interaction, and examine its influence across a broader range of chemistry topics.

In conclusion, this study provides strong empirical evidence that social interaction is a critical factor in determining students' chemistry learning outcomes. The significant influence of social interaction highlights the importance of incorporating interactive learning processes in classroom practice. By optimizing social interaction, educators can enhance students' conceptual understanding and overall academic achievement, particularly in complex and abstract topics such as buffer solutions.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results and discussion of this study, it can be concluded that social interaction has a significant influence on students' chemistry learning outcomes in buffer solution topics at the secondary school level. This conclusion is supported by the existence of statistically significant differences in learning outcomes among students with high, moderate, and low levels of social interaction. Students with high levels of social interaction achieved better learning outcomes compared to those in the moderate and low categories, while students with low social interaction demonstrated the lowest performance. These findings indicate that social interaction functions as a crucial predictor of learning achievement, in which higher levels of interaction are associated with improved academic outcomes. Therefore, learning processes that actively involve interaction among students are capable of facilitating deeper conceptual understanding, particularly in complex chemistry topics such as buffer solutions.

Furthermore, the study reveals that the influence of social interaction on learning outcomes is consistent and independent of the instructional model employed. This finding highlights that social interaction can be regarded as a fundamental component in the learning process. From a theoretical perspective, this result reinforces the principles of social constructivism, which posit that learning is an active process constructed through interaction among individuals. Consequently, efforts to improve students' chemistry learning outcomes should not rely solely on the selection of instructional models but should also emphasize the optimization of students' social interaction during the learning process.

Based on these conclusions, several recommendations can be proposed. First, teachers are encouraged to design and implement instructional strategies that actively promote social interaction, such as group discussions, collaborative learning activities, and teamwork-based tasks that foster active student participation. In addition, teachers should create a supportive and interactive learning environment that encourages students to communicate, exchange ideas, and collaborate effectively. Second, future researchers are advised to conduct studies with broader scopes, including larger and more diverse samples, as well as different chemistry topics, in order to enhance the generalizability of findings. Moreover, future studies should consider employing multiple methods for measuring social interaction to obtain more comprehensive and objective data. Further research may also explore the role of social interaction in relation to other variables, such as learning motivation, critical thinking skills, and problem-solving abilities, thereby enriching the understanding of factors influencing students' chemistry learning outcomes.

FURTHER STUDY

Despite the significant findings of this study, several limitations should be acknowledged, including the relatively limited sample drawn from a single school, the reliance on self-reported questionnaires to measure social interaction, and the focus on a single chemistry topic, which may restrict the generalizability of the results. Additionally, other variables that may influence learning outcomes, such as motivation, prior knowledge, and cognitive ability, were not explicitly examined. Therefore, future research is recommended to involve larger and more diverse samples across different educational contexts, employ mixed-method approaches combining quantitative and qualitative data to capture the complexity of social interaction, and investigate its effects across various chemistry topics and educational levels. Further studies may also explore the relationship between social interaction and other relevant variables, such as critical thinking and problem-solving skills, as well as conduct longitudinal research to examine its long-term impact on students

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