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Improving Chemical Bonding Conceptual Understanding Using STAD Cooperative Learning Assisted by Interactive Media

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ABSTRACT

Purpose of the study: This study aims to investigate the effectiveness of the Cooperative Learning model type STAD supported by interactive presentation media on students' conceptual understanding of chemical bonding.

Methodology: A quasi-experimental design with a non-equivalent control group was employed, involving two groups of secondary school students. The experimental group was taught using the STAD model integrated with interactive media, while the control group received conventional instruction. Data were collected through pre-test and post-test instruments, which were validated and tested for reliability.

Main Findings: The results showed that the experimental group achieved a higher post-test mean score (82.13) compared to the control group (68.27), with an N-gain of 0.67 indicating medium–high improvement. Statistical analysis revealed a significant difference between the two groups ($p < 0.05$), confirming the effectiveness of the intervention.

Novelty/Originality of this study: The novelty of this study lies in the integration of cooperative learning and interactive media with a specific focus on conceptual understanding in chemical bonding. These findings suggest that such an approach can significantly enhance students' learning outcomes in chemistry education.

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1. INTRODUCTION

Chemistry education plays a crucial role in developing students' scientific literacy, particularly in fostering conceptual understanding of abstract phenomena at the molecular level [1]-[3]. One of the fundamental topics in secondary school chemistry is chemical bonding, which underpins students' comprehension of molecular structure, properties of matter, and chemical reactivity [4]-[6]. However, mastering this topic requires learners to integrate symbolic, macroscopic, and submicroscopic representations, a process that is often cognitively demanding [7]-[9]. As a result, students frequently encounter difficulties in constructing accurate mental models of chemical bonds, which may hinder their overall achievement in chemistry.

Despite its importance, numerous studies have reported that students' understanding of chemical bonding remains superficial and fragmented [10], [11]. Learners tend to rely on rote memorization rather than meaningful conceptualization, leading to persistent misconceptions such as confusion between ionic and covalent bonds or misunderstanding electron sharing and transfer processes [12]-[14]. These issues are often exacerbated by teacher-centered instructional practices that limit student engagement and interaction [15]-[17]. Consequently, there is a pressing need for instructional approaches that actively involve students in the learning process and promote deeper conceptual understanding.

One promising approach is cooperative learning, particularly the Student Teams Achievement Divisions (STAD) model. STAD emphasizes collaboration among students in small heterogeneous groups, encouraging peer instruction, discussion, and shared responsibility for learning outcomes [18]-[20]. Through structured group activities, students are expected to actively construct knowledge, clarify misunderstandings, and reinforce their conceptual understanding [21]-[23]. Previous research has demonstrated that cooperative learning can improve academic achievement, motivation, and social skills; however, its effectiveness is highly dependent on how it is implemented in specific subject contexts.

In context of chemistry learning, the integration of instructional media is equally important. Interactive presentation media, such as digital slides enriched with animations, visualizations, and structured content, can help bridge the gap between abstract concepts and students' understanding. These media provide visual representations of microscopic processes, enabling learners to better grasp complex ideas such as electron interactions and bond formation [24], [25]. When combined with cooperative learning strategies, interactive media have the potential to create a more engaging and meaningful learning environment.

However, existing studies tend to examine cooperative learning models and instructional media separately, with limited focus on their combined effect in chemistry education [26]. Moreover, many previous investigations have emphasized general academic achievement rather than specifically targeting conceptual understanding, which is a critical outcome in science learning [27], [28]. This gap highlights the need for more focused research that explores how the integration of STAD and interactive presentation media influences students' conceptual mastery, particularly in challenging topics like chemical bonding.

Therefore, this study aims to examine the effectiveness of the STAD cooperative learning model supported by interactive presentation media in improving students' conceptual understanding of chemical bonding. The novelty of this research lies in the integration of collaborative learning strategies with interactive digital media, as well as its focus on conceptual understanding as a primary learning outcome. By addressing both pedagogical and technological dimensions, this study seeks to contribute to the development of more effective instructional practices in chemistry education.

The urgency of this research is underscored by the need to enhance the quality of chemistry learning and to equip students with a deeper understanding of fundamental concepts. Improving conceptual mastery in chemical bonding is essential not only for academic success but also for developing higher-order thinking skills required in science and technology fields. The findings of this study are expected to provide valuable insights for educators, curriculum developers, and policymakers in designing innovative and effective chemistry learning strategies that are responsive to students' needs.

2. RESEARCH METHOD

Study employed a quasi-experimental design with a non-equivalent control group to examine the effectiveness of the Cooperative Learning model type STAD supported by interactive presentation media on students' conceptual understanding of chemical bonding. The design was selected due to the practical constraints of random assignment in a natural classroom setting [24]-[30]. Two intact classes were assigned as the experimental group and the control group [31], [32]. The experimental group received instruction through the STAD model integrated with interactive presentation media, while the control group was taught using conventional teacher-centered methods.

Research was conducted at Sultan Hassan Secondary School, Temburong District. The participants consisted of secondary school students enrolled in a chemistry course covering the topic of chemical bonding. A purposive sampling technique was used to select two classes with relatively similar academic characteristics based on prior achievement records. Each group consisted of approximately equal numbers of students to ensure comparability. Before the intervention, both groups were administered a pre-test to assess their initial conceptual understanding and to establish baseline equivalence [30], [33].

The treatment was implemented over several instructional sessions focusing on ionic bonding, covalent bonding, and metallic bonding. In the experimental group, learning activities followed the structured stages of the STAD model, including class presentation, team study, quizzes, individual improvement scores, and group recognition. Interactive presentation media were utilized to deliver visual explanations, animations, and guided problem-solving activities. These media were designed to facilitate students' understanding of submicroscopic processes, such as electron transfer and sharing. In contrast, the control group received instruction through lectures, textbook explanations, and limited question–answer sessions without structured cooperative learning or interactive media.

To measure students' conceptual understanding, a conceptual test was developed based on key indicators of chemical bonding. The instrument consisted of multiple-choice and short-answer questions designed to assess students' ability to explain concepts, interpret representations, and apply their knowledge in different contexts. The development of the instrument followed a systematic process, including blueprint construction, expert validation, pilot testing, and item analysis.

The following table presents the test blueprint (instrument grid) used to ensure alignment between learning indicators and assessment items.

Table 1. Instrument Blueprint for Conceptual Understanding of Chemical Bonding

No	Indicator of Conceptual Understanding	Subtopic	Item Type	Item Number
1	Explaining the concept of ionic bonding	Ionic Bonding	Multiple Choice	1, 2, 3
2	Distinguishing ionic and covalent bonds	Ionic & Covalent	Multiple Choice	4, 5
3	Describing electron transfer and sharing mechanisms	Bond Formation	Short Answer	6, 7
4	Interpreting Lewis structures	Covalent Bonding	Multiple Choice	8, 9
5	Analyzing properties based on bonding types	All Subtopics	Short Answer	10, 11

The validity of the instrument was established through content and construct validation. Content validity was evaluated by three experts in chemistry education, who reviewed the alignment between items and learning objectives, clarity of language, and scientific accuracy. Aiken's V coefficient was calculated, and all items achieved a value above the acceptable threshold ($V > 0.80$), indicating high content validity. Construct validity was examined through a pilot test administered to students outside the sample, followed by item discrimination and difficulty index analysis. Items that did not meet the criteria were revised or discarded.

Reliability analysis was conducted using Cronbach's Alpha to determine the internal consistency of the instrument. The results indicated a reliability coefficient greater than 0.70, which is considered acceptable for educational research. The following table summarizes the results of the validity and reliability testing.

Table 2. Summary of Instrument Validity and Reliability

Aspect	Method Used	Result	Interpretation
Content Validity	Aiken's V	> 0.80	Highly Valid
Construct Validity	Item Analysis	Valid Items	Acceptable
Reliability	Cronbach's Alpha	> 0.70	Reliable

Data collection was carried out in three stages: pre-test, treatment, and post-test. The pre-test was administered before the intervention to both groups to assess initial equivalence. After the instructional treatment, a post-test with equivalent difficulty was given to measure students' conceptual understanding. In addition, classroom observations were conducted to ensure the fidelity of the STAD implementation and to monitor student engagement during the learning process.

The data analysis techniques were selected to address the research objectives comprehensively. First, descriptive statistics were used to summarize students' scores, including mean, standard deviation, and gain scores. To measure the improvement in conceptual understanding, the normalized gain (N-gain) was calculated. Second, inferential statistical analysis was conducted using an independent samples t-test to compare the post-test scores between the experimental and control groups. Prior to hypothesis testing, assumptions of normality and homogeneity of variance were examined using appropriate statistical tests.

The following table outlines the data analysis procedures used in this study.

Table 3. Data Analysis Techniques

Objective	Analysis Technique	Description
Measuring initial equivalence	Pre-test comparison	Independent t-test
Measuring learning improvement	N-gain analysis	Categorization (low, medium, high)
Testing hypothesis	Post-test comparison	Independent t-test
Checking assumptions	Normality & Homogeneity	Shapiro-Wilk & Levene's Test

To provide a clear overview of the research procedure, the structure of the study is illustrated in the following diagram.

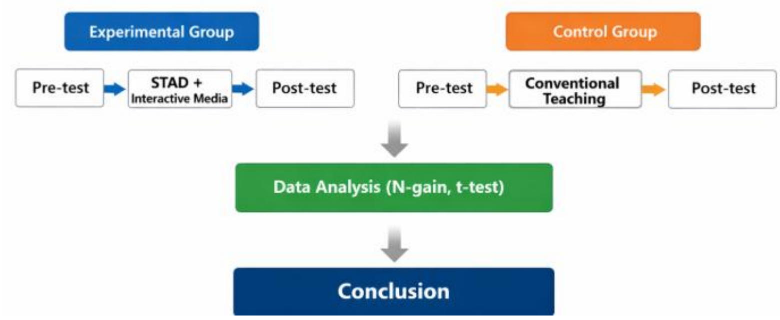

Figure 1. Research Design Structure

Overall, this methodology was designed to ensure rigor, transparency, and alignment with the research objectives. By combining a structured experimental design, validated instruments, and appropriate data analysis techniques, the study aims to produce reliable and meaningful findings regarding the effectiveness of the STAD cooperative learning model supported by interactive presentation media in chemistry education.

3. RESULTS AND DISCUSSION

This section presents the findings of the study based on the data collected through pre-test and post-test assessments, supported by statistical analysis and qualitative insights. The results are organized systematically to address the research objectives, namely examining the effectiveness of the STAD cooperative learning model supported by interactive presentation media on students' conceptual understanding of chemical bonding. The results are presented in Table 4.

Table 4. Pre-test Scores of Experimental and Control Groups

Group	N	Mean Score	Standard Deviation
Experimental Group	30	45.67	8.12
Control Group	30	44.93	7.95

Data in Table 4 indicate that the mean scores of both groups were relatively similar prior to the intervention. The experimental group obtained a mean score of 45.67, while the control group scored 44.93. This suggests that both groups had comparable initial abilities in understanding chemical bonding concepts. To statistically confirm this equivalence, an independent samples t-test was conducted.

Table 5. Independent Samples t-test for Pre-test Scores

Variable	t-value	Sig. (p-value)	Interpretation
Pre-test	0.352	0.726	No significant difference

The p-value ($0.726 > 0.05$) indicates that there was no statistically significant difference between the two groups at the beginning of the study. Therefore, both groups can be considered equivalent prior to the treatment. After the implementation of the instructional treatment, a post-test was administered to measure students' conceptual understanding.

Table 6. Post-test Scores of Experimental and Control Groups

Group	N	Mean Score	Standard Deviation
Experimental Group	30	82.13	6.45
Control Group	30	68.27	7.21

As shown in Table 6, the experimental group achieved a significantly higher mean score (82.13) compared to the control group (68.27). This indicates that students who were taught using the STAD model with interactive presentation media demonstrated better conceptual understanding of chemical bonding. To measure the magnitude of improvement in students' conceptual understanding, normalized gain (N-gain) scores were calculated.

Table 7. N-Gain Scores of Experimental and Control Groups

Group	Mean N-Gain	Category
Experimental Group	0.67	Medium–High
Control Group	0.42	Medium

The results in Table 7 show that the experimental group achieved a higher N-gain score (0.67), categorized as medium–high improvement, while the control group obtained a moderate improvement (0.42). This finding indicates that the STAD model supported by interactive media was more effective in enhancing students' conceptual understanding. To visualize the improvement, the following graph illustrates the comparison between pre-test and post-test scores.

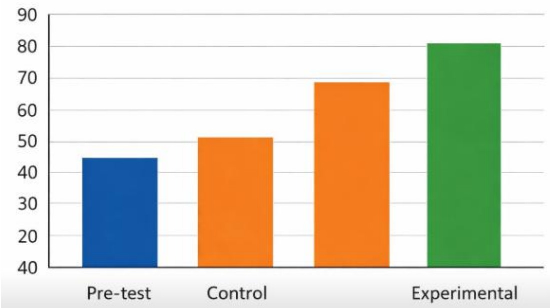

Figure 8. Comceptual Understanding Score

The graph clearly shows a sharper increase in the experimental group compared to the control group. To determine whether the observed differences were statistically significant, an independent samples t-test was conducted on the post-test scores. The results are presented in Table 9.

Table 9. Independent Samples t-test for Post-test Scores

Variable	t-value	Sig. (p-value)	Interpretation
Post-test	7.214	0.000	Significant difference

P-value (0.000 < 0.05) indicates a statistically significant difference between the experimental and control groups. Therefore, the null hypothesis is rejected, and it can be concluded that the STAD cooperative learning model supported by interactive presentation media significantly improves students' conceptual understanding of chemical bonding. Further analysis was conducted to examine students' performance across different indicators of conceptual understanding. The results are presented in Table 10.

Table 10. Achievement by Conceptual Indicators

Indicator	Experimental (%)	Control (%)
Explaining ionic bonding	85	72
Distinguishing bond types	83	70
Electron transfer and sharing	80	65
Interpreting Lewis structures	84	69
Analyzing bonding properties	78	66

Table 11 shows that the experimental group outperformed the control group across all indicators. The largest difference was observed in the ability to explain electron transfer and sharing, which is a key submicroscopic concept in chemical bonding. Classroom observations were conducted to ensure the proper implementation of the STAD model and to evaluate student engagement. The results are summarized in Table 12.

Table 12. Observation of Learning Activities

Aspect Observed	Experimental Group	Control Group
Student participation	High	Moderate
Group interaction	Very active	Limited
Concept discussion	Deep	Surface-level
Use of visual media	Intensive	Minimal

Observation results indicate that students in the experimental group were more actively engaged in learning activities. The use of interactive media and group discussions facilitated deeper conceptual exploration compared to the control group. To complement the quantitative findings, semi-structured interviews were conducted with selected students from the experimental group. The results are presented in Table 8.

Table 13. Summary of Student Interview Responses

Question Aspect	Student Response Summary
Learning experience	More enjoyable and engaging
Understanding of concepts	Easier to visualize abstract concepts
Group learning	Helpful for discussing and clarifying ideas
Media usage	Animations helped understanding electron movement

Iinterview results reveal that students perceived the learning approach as engaging and helpful in understanding abstract chemical concepts. They particularly emphasized the role of visual media and peer discussion in enhancing their comprehension.

Findings of this study demonstrate that the implementation of the STAD cooperative learning model supported by interactive presentation media significantly enhances students' conceptual understanding of chemical bonding. This is evidenced by the substantial difference in post-test scores between the experimental and control groups, as well as the higher N-gain achieved by students exposed to the intervention. The improvement observed in the experimental group indicates that the integration of collaborative learning structures and visual-based instructional media effectively facilitates deeper understanding of abstract chemical concepts, particularly those involving submicroscopic representations such as electron transfer and sharing.

These results are consistent with prior studies in chemistry education which emphasize that cooperative learning environments can promote active engagement, peer instruction, and meaningful knowledge construction. The STAD model, in particular, has been widely recognized for its structured approach in fostering individual accountability and group collaboration [34]. In the context of chemical bonding, where students often struggle with conceptual visualization, the opportunity to discuss and negotiate meaning within groups appears to reduce misconceptions and strengthen conceptual clarity [35]. Furthermore, previous research has highlighted that students who participate in cooperative learning tend to achieve better academic outcomes compared to those in traditional lecture-based settings, which aligns with the findings of this study.

In addition to the cooperative learning component, the use of interactive presentation media plays a crucial role in enhancing students' understanding. Chemistry, as a discipline, requires the integration of multiple levels of representation macroscopic, symbolic, and submicroscopic [36], [37]. The visual and dynamic features of interactive media, such as animations and diagrams, help bridge the gap between these representations [38]. The results of this study support earlier findings that visualizations significantly improve students' ability to interpret abstract chemical processes. In particular, the higher achievement in indicators related to electron transfer and Lewis structure interpretation suggests that the media used in this study successfully supported students in constructing accurate mental models [39], [40].

A key contribution and novelty of this research lies in the integrated application of the STAD cooperative learning model with interactive presentation media, specifically targeting conceptual understanding in chemical bonding. While previous studies have examined cooperative learning or instructional media independently, this study combines both approaches within a single instructional framework. Moreover, the focus on conceptual understanding as opposed to general academic achievement adds depth to the investigation, as it addresses a core challenge in chemistry education. The context-specific implementation in Sultan Hassan Secondary School also provides empirical evidence from a relatively underexplored educational setting, thereby enriching the existing literature with new insights.

From a pedagogical perspective, the findings of this study have important implications for chemistry teaching practices. In the short term, the integration of STAD and interactive media can increase student engagement, participation, and immediate learning outcomes. Students become more actively involved in the learning process, which enhances motivation and fosters a more student-centered classroom environment. In the long term, improving students' conceptual understanding of foundational topics such as chemical bonding can contribute to better performance in more advanced chemistry topics, as well as the development of higher-order thinking skills. This approach also aligns with contemporary educational goals that emphasize collaboration, critical thinking, and the effective use of technology in learning.

Despite these contributions, several limitations should be acknowledged. First, the study was conducted within a limited sample size and in a single school context, which may affect the generalizability of the findings. Differences in student characteristics, teacher expertise, and school resources may influence the effectiveness of the intervention in other settings. Second, the duration of the intervention was relatively short, focusing only on the topic of chemical bonding. A longer implementation period may provide a more comprehensive understanding of the sustained impact of the instructional approach. Third, while the study focused on conceptual understanding, other important learning outcomes such as attitudes toward chemistry, collaborative skills, and long-term retention were not extensively examined.

In light of these limitations, future research is recommended to expand the scope of investigation by involving multiple schools, larger sample sizes, and diverse student populations. Additionally, further studies could explore the long-term effects of integrating cooperative learning and interactive media, as well as its impact on other dimensions of learning in chemistry education. Nevertheless, the present study provides strong evidence that combining the STAD model with interactive presentation media is an effective strategy for improving students' conceptual understanding, particularly in complex and abstract topics such as chemical bonding.

4. CONCLUSION

This study aimed to examine the effectiveness of the STAD cooperative learning model supported by interactive presentation media in improving students' conceptual understanding of chemical bonding. The findings indicate that the experimental group achieved a significantly higher post-test mean score (82.13) compared to the control group (68.27), with an N-gain of 0.67 categorized as medium–high improvement. Statistical analysis confirmed a significant difference between the two groups ($p < 0.05$), demonstrating that the integration of STAD and interactive media effectively enhances students' mastery of chemical bonding concepts. These results highlight that combining collaborative learning strategies with visual-based instructional support facilitates deeper conceptual comprehension, particularly in abstract chemistry topics. It is recommended that chemistry teachers adopt cooperative learning models integrated with interactive media to improve students' engagement and conceptual understanding. Future research should explore broader contexts and longer implementation periods to examine the sustainability and wider applicability of this approach.

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AUTHOR CONTRIBUTIONS

Conceptualization, S.T. and L.A.M.; Methodology, S.T.; Software, S.T.; Validation, S.T. and L.A.M.; Formal Analysis, S.T.; Investigation, S.T.; Resources, L.A.M.; Data Curation, S.T.; Writing – Original Draft Preparation, S.T.; Writing – Review & Editing, S.T. and L.A.M.; Visualization, S.T.; Supervision, L.A.M.; Project Administration, S.T.; Funding Acquisition, L.A.M.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

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