Journal of Chemical Learning Innovation
Vol. 2, No. 2, December 2025, pp. 162~171
ISSN: 3063-0886, DOI:10.37251/jocli.v2i2.2576

Enhancing Students' Conceptual Understanding of Colloidal Systems through Inquiry-Based Chemistry Instruction

Rajendra Nivrutti Shirsat[1], and Sang Yeon Lee[2]
[1]School of Chemical Sciences, Goa University, India
[2]The School of Applied Chemical Engineering, Kyungpook National University, South Korea

Article Info

Article history:

Received Aug 12, 2025
Revised Oct 5, 2025
Accepted Nov 20, 2025
OnlineFirst Dec 30, 2025

Keywords:

Chemistry Education
Conceptual Understanding
Colloidal Systems
Inquiry-Based Learning
Secondary school students

ABSTRACT

Purpose of the study: This study aimed to examine the effect of inquiry-based chemistry learning on secondary school students' conceptual understanding of colloidal systems.

Methodology: A quasi-experimental design employing a pretest–posttest control group was used. Data were collected using a validated conceptual understanding test and a diagnostic questionnaire. The data were analyzed using N-gain analysis and an independent samples *t*-test at a 0.05 significance level after confirming the assumptions of normality and homogeneity.

Main Findings: The results indicate that inquiry-based learning significantly improved students' conceptual understanding. A total of 67.5% of students achieved scores above the minimum competency standard, while 92.5% demonstrated a moderate level of conceptual improvement. The *t*-test results ($t_{(calculated)}$ = 4.84 > $t_{(table)}$ = 2.68) confirmed a statistically significant difference between pretest and posttest scores.

Novelty/Originality of this study: The novelty of this study lies in the application of a contextually adapted guided inquiry model supported by validated diagnostic instruments. This approach provides robust empirical evidence on how inquiry-based learning facilitates students' construction of chemical concepts, thereby contributing to both theoretical and practical advancements in chemistry education.

Corresponding Author:
Rajendra Nivrutti Shirsat,
School of Chemical Sciences, Goa University, Teleiogao Plateau, Goa - 403 206, Goa, India.
Email: rjnivruttishrt45@gmail.com

1. INTRODUCTION

Chemistry plays a fundamental role in explaining natural phenomena and technological processes encountered in everyday life [1], [2]. As a core science subject, chemistry education aims not only to transmit factual knowledge but also to develop students' deep conceptual understanding of chemical principles [3], [4]. However, learning chemistry remains challenging for many students due to the abstract nature of its concepts and the need to integrate macroscopic observations, submicroscopic representations, and symbolic expressions [5], [6]. This complexity often results in superficial learning, where students rely on memorization rather than meaningful conceptual construction.

One persistent issue in secondary chemistry education is students' limited conceptual understanding, particularly in abstract topics such as colloidal systems [7], [8]. Colloids require learners to interpret phenomena that are not directly observable while simultaneously linking experimental evidence with theoretical explanations. Previous studies have reported that students frequently experience misconceptions related to particle size, dispersion phases, and the properties of colloidal systems [9], [10]. These difficulties are often exacerbated by traditional teacher-centered instructional approaches that emphasize lecturing and algorithmic problem-solving, providing limited opportunities for students to actively engage in scientific reasoning [11], [12].

Contemporary perspectives on science education emphasize the importance of learner-centered pedagogies that support knowledge construction through active involvement [13], [14]. Inquiry-based learning has been widely recognized as an instructional approach aligned with constructivist learning theory, which views learning as an active process of meaning-making [15], [16]. Through inquiry-based learning, students are encouraged to formulate questions, design investigations, analyze data, and communicate scientific explanations [17], [18]. Such processes enable learners to develop a deeper understanding of chemical concepts while fostering higher-order thinking skills and scientific literacy.

Empirical evidence suggests that inquiry-based learning can positively influence students' achievement, engagement, and conceptual understanding in science education [19], [20]. Several studies have demonstrated that inquiry-oriented instruction enhances students' ability to connect theoretical knowledge with experimental observations and reduces common misconceptions [21], [22]. Nevertheless, many existing studies focus primarily on general learning outcomes or procedural skills, while relatively few explicitly examine students' conceptual understanding in specific chemistry topics using validated diagnostic instruments [23], [24]. Moreover, research on inquiry-based chemistry learning in secondary education remains context-dependent, highlighting the need for further empirical investigation.

Despite the growing interest in inquiry-based approaches, gaps remain between students' procedural performance and their conceptual understanding [25], [26]. Students may achieve satisfactory test scores while still holding fragmented or incorrect conceptions of chemical phenomena. This issue underscores the importance of employing assessment tools capable of capturing the depth of students' conceptual understanding rather than surface-level recall [27], [28]. Diagnostic instruments, when integrated with inquiry-based instruction, offer valuable insights into how students construct and reorganize their chemical knowledge [29], [30].

Despite the extensive body of research highlighting the benefits of inquiry-based learning in science education, several critical gaps remain within the context of secondary chemistry instruction, particularly in relation to students' conceptual understanding of colloidal systems [7], [31]. Many existing studies predominantly focus on general learning outcomes, procedural skills, or students' engagement, without sufficiently examining how inquiry-based approaches support the reconstruction of students' chemical concepts at multiple representational levels. Moreover, research that specifically integrates validated diagnostic instruments to uncover persistent misconceptions in colloidal chemistry is still limited and context-dependent. As a result, there is a lack of empirical evidence that systematically explains how inquiry-based learning influences both conceptual gains and the nature of students' remaining misunderstandings in abstract chemistry topics.

The novelty of this study lies in its contextually adapted implementation of guided inquiry-based chemistry instruction combined with the use of validated conceptual and diagnostic assessment instruments to capture students' conceptual development in a nuanced manner. Unlike prior studies that rely primarily on achievement scores, this research emphasizes conceptual understanding as a core learning outcome and provides detailed insights into students' learning progress across specific conceptual indicators of colloidal systems. By triangulating quantitative learning gains with diagnostic evidence of students' reasoning, this study offers a more comprehensive perspective on the effectiveness of inquiry-based learning in chemistry education.

The urgency of this research is underscored by the persistent challenges faced by students in mastering abstract chemical concepts that require integration across macroscopic, submicroscopic, and symbolic representations. In the context of secondary education, inadequate conceptual understanding of foundational topics such as colloids can hinder students' progression to more advanced chemical concepts and negatively impact scientific literacy. Therefore, investigating instructional approaches that not only improve test performance but also foster meaningful and coherent conceptual understanding is essential. This study responds to this need by providing empirical evidence to inform chemistry educators and curriculum designers on the pedagogical potential of inquiry-based learning to enhance conceptual understanding and address enduring misconceptions in chemistry classrooms.

Therefore, this study aims to investigate the effect of inquiry-based chemistry learning on secondary school students' conceptual understanding of colloidal systems. Using a quasi-experimental design with validated conceptual and diagnostic instruments, this research examines whether inquiry-based instruction leads to significant improvements in students' conceptual understanding compared to conventional teaching methods [32], [33]. By providing empirical evidence on the effectiveness of inquiry-based learning in chemistry education, this study contributes to the growing body of literature on innovative instructional strategies and offers practical implications for chemistry educators seeking to promote meaningful learning and conceptual development.

2. RESEARCH METHOD

2.1. Type of Research

This study employed a quantitative approach using a quasi-experimental design, specifically a pretest–posttest control group design [34], [35]. This design was selected to examine the effect of inquiry-based chemistry learning on students' conceptual understanding while maintaining the natural classroom setting without random assignment of participants. The use of a control group enabled a systematic comparison between inquiry-based instruction and conventional teaching methods.

2.2. Population and Sample

The study was conducted at a public secondary school in Goa, India. The participants consisted of students taking chemistry subjects. A total of 40 students participated in the study and were selected using purposive sampling, based on the similarity of their academic backgrounds and prior chemistry achievement. The selected class was deemed appropriate due to its comparable initial conceptual understanding level and the availability of instructional support for implementing inquiry-based learning [36], [37]. All participants had previously received instruction on foundational chemistry topics but had not been formally introduced to inquiry-based learning strategies.

2.3. Instruments and Data Collection

Data were collected using two primary instruments designed to comprehensively assess students' conceptual understanding of colloidal systems and to support the quantitative findings of the study [38], [39]. The first instrument was a conceptual understanding test, consisting of multiple-choice items focused on key indicators of conceptual knowledge, including the classification of colloids, colloidal properties, preparation methods, and real-world applications. The test items were developed based on curriculum standards and relevant chemistry education literature and were reviewed by subject-matter experts to ensure content validity and alignment with learning objectives [40], [41]. Prior to implementation, the instrument was piloted to examine its reliability and clarity.

The second instrument was a diagnostic questionnaire aimed at capturing students' conceptual reasoning and identifying common misconceptions encountered during inquiry-based learning activities. The questionnaire provided complementary data by eliciting students' responses to conceptual scenarios related to colloidal phenomena and their learning experiences throughout the instructional process. Both instruments were administered as pretests before the instructional intervention and as posttests after the completion of the inquiry-based learning sessions. The data collected from these instruments served as the basis for evaluating changes in students' conceptual understanding and for determining the effectiveness of inquiry-based chemistry learning. The following is a grid of learning outcome test instruments:

Tabel 1. Learning Outcome Test Instrument Grid

No.	Indicator	Cognitive Level			Amount
		C_1	C_2	C_3	
1	Classification of colloidal systems	2,4,6	1,3,5		6
2	Types of colloids	7,8,9,10,11,12,13			7
3	Preparation methods	14		15,16,17,18,19	6
4	Colloidal properties	20,21,22	23,24,2,26,27		8
5	Applications of colloids			28,29,30	3
	Amount	14	8	8	30

2.4. Data Analysis Techniques

The collected data were analyzed using both descriptive and inferential statistical techniques. Prior to hypothesis testing, normality and homogeneity tests were conducted to ensure that the data met the assumptions for parametric analysis [42], [43]. Students' learning gains were calculated using N-gain analysis to determine the magnitude of conceptual improvement. To examine the statistical significance of differences between pretest and posttest scores, an independent samples t-test was performed at a 0.05 significance level. The results of these analyses were used to determine the effectiveness of inquiry-based chemistry learning in enhancing students' conceptual understanding of colloidal systems.

2.5. Prosedur Penelitian

The research procedure consists of three main stages, namely the preparation, implementation, and evaluation stages. In the preparation stage, learning tools and research instruments are prepared, and coordination with chemistry teachers at the school is carried out. The implementation stage includes the application of an inquiry-based learning model in the experimental class. The inquiry model used refers to the syntax developed by Joyce and Weil, which consists of five main stages: (1) formulating the problem or research question (problem identification), (2) designing a temporary hypothesis (formulating hypothesis), (3) planning and carrying out experiments or investigations (data collection), (4) analyzing data and drawing conclusions (data interpretation), and (5) communicating the findings (reflection and communication). This model is designed to encourage active student involvement in constructing knowledge based on the results of scientific investigations of chemical phenomena. In the evaluation stage, data on learning outcomes and student feedback are collected through prepared instruments. The research procedure can be seen in the following flowchart.

Figure 1. Research Procedure

3. RESULTS AND DISCUSSION

To provide an overview of students' conceptual understanding of colloidal systems before and after the instructional intervention, descriptive statistical analyses were conducted. The analysis focused on key measures, including the mean, standard deviation, and score range, to capture changes in students' conceptual performance resulting from the implementation of inquiry-based chemistry learning. A summary of the descriptive statistics for the pretest and posttest scores is presented in Table 1.

Table 1. Descriptive Statistics of Students' Conceptual Understanding Scores

Test	N	Mean	SD	Minimum	Maximum
Pretest	40	48.1	8.4	30	63
Posttest	40	72.9	9.1	50	96

Table 1 shows a clear improvement in students' conceptual understanding of colloidal systems following the implementation of inquiry-based chemistry learning. The mean posttest score was substantially higher than the mean pretest score, indicating a notable increase in overall conceptual mastery. In addition, the range of scores shifted upward, as reflected by higher minimum and maximum posttest scores, suggesting that improvement occurred across students with varying initial ability levels. The comparable standard deviations between the pretest and posttest indicate a relatively consistent distribution of scores, implying that the learning gains were experienced by most students rather than being limited to a small subgroup.

After calculations were carried out using the percentage formula for understanding the concept for each indicator, the results of students' understanding of the concept for each indicator were obtained as in the following table:

Tabel 2. Students' Conceptual Understanding Across Indicators

Conceptual Indicator	Pretest (%)	Posttest (%)
Classification of colloidal systems	26	84
Types of colloids	15	86
Preparation methods	10	80
Colloidal properties	12	28
Applications of colloids	45	91
Overall Mean	21.6	73.8

Table 2 illustrates differential improvements in students' conceptual understanding across the assessed indicators following inquiry-based chemistry instruction. Substantial gains were observed in indicators related to the classification of colloidal systems, types of colloids, and their real-world applications. These improvements suggest that inquiry-based learning effectively supported students in connecting observable phenomena with conceptual categories, particularly when concepts were grounded in familiar or contextual examples.

Moderate improvements were also evident in students' understanding of colloidal preparation methods, indicating that guided inquiry activities facilitated procedural understanding through hands-on investigation and collaborative reasoning. However, comparatively lower gains were found in indicators related to colloidal properties, which require students to integrate macroscopic observations with submicroscopic and symbolic representations. This finding highlights a common challenge in chemistry learning, where abstract conceptualization demands higher levels of cognitive processing and representational competence.

The variation in conceptual gains across indicators underscores the importance of structured scaffolding within inquiry-based instruction. While inquiry learning promotes active knowledge construction, complex conceptual domains such as colloidal properties may require additional instructional support to help students bridge multiple levels of chemical representation. Overall, the results presented in Table 2 demonstrate that inquiry-based learning is particularly effective in enhancing context-based and classification-oriented conceptual understanding, while also revealing areas that warrant further pedagogical attention.

To further examine students' conceptual understanding and identify potential misconceptions related to colloidal systems, a diagnostic questionnaire was administered following the instructional intervention. The questionnaire consisted of dichotomous (Yes/No) statements designed to capture students' interpretations of key colloidal concepts based on illustrations, readings, discussions, and experimental activities. A summary of students' responses to the diagnostic questionnaire is presented in Table 3.

Tabel 3. Students' Responses to Diagnostic Questionnaire on Colloidal Concepts

No.	Statement	Yes (%)	No (%)
1	After the teacher provided illustrations about colloids, I became interested in learning more about colloids.	62.5	37.5
2	After the presentation of images/illustrations, I was unable to visualize what a colloidal system actually is.	10.0	90.0
3	After reading textbooks and supplementary materials, I was able to predict what would happen when oil is mixed with citrus juice.	79.0	21.0
4	Through the Tyndall effect experiment, I understood that milk and emulsions scatter light when illuminated.	95.0	5.0
5	After reading and discussing with peers, I was still unable to distinguish between true solutions, suspensions, and colloids.	65.0	35.0
6	After conducting the coagulation experiment, I understood how an egg coagulates when boiled.	77.5	22.5
7	After performing the Tyndall effect experiment, I understood why fog appears more visible at night than during the day.	72.5	27.5
8	Based on the colloid experiment, I concluded that mango juice preparation represents a condensation method of colloid formation.	40.0	60.0
9	Based on the experiment, I understood that colloids are mixtures that can be separated using ultrafiltration.	80.0	20.0
10	The process of making pudding from agar powder into a gel represents a coagulation phenomenon.	82.0	18.0

The responses presented in Table 3 provide additional insight into students' conceptual understanding and remaining misconceptions regarding colloidal systems after the implementation of inquiry-based learning. Overall, the results indicate that most students were able to interpret colloidal phenomena meaningfully when concepts were supported by visual representations and experimental activities. High levels of affirmative responses to items related to the Tyndall effect and coagulation experiments suggest that hands-on inquiry effectively facilitated students' understanding of observable colloidal properties.

Students' strong agreement with statements concerning light scattering in milk and emulsions, as well as the visibility of fog under different lighting conditions, indicates that inquiry-based experiments helped bridge macroscopic observations with conceptual explanations. Similarly, positive responses related to coagulation phenomena, such as egg solidification and gel formation, demonstrate that contextualized experiments supported students in recognizing real-world manifestations of colloidal behavior.

However, the findings also reveal the persistence of certain misconceptions. A considerable proportion of students reported difficulty distinguishing between true solutions, suspensions, and colloids, suggesting that classification-related concepts remain challenging despite inquiry-based instruction. In addition, the relatively low agreement regarding the identification of colloid formation through condensation in everyday processes, such as mango juice preparation, indicates that abstract or less explicitly demonstrated processes may require more structured guidance. These results highlight that while inquiry-based learning promotes conceptual understanding, it does not automatically eliminate all misconceptions, particularly those involving abstract classification and submicroscopic reasoning.

Taken together, the results from Table 3 complement the quantitative learning gains reported earlier by illustrating how inquiry-based instruction influences students' conceptual interpretations at a finer-grained level. The diagnostic responses underscore the importance of integrating explicit conceptual scaffolding within inquiry activities to support students in refining their understanding and resolving persistent misconceptions in colloidal chemistry.

Prior to testing the research hypothesis, preliminary statistical analyses were conducted to ensure that the data met the assumptions required for parametric testing. Specifically, tests of normality and homogeneity of variance were performed on the pretest and posttest scores. After confirming that these assumptions were satisfied, inferential statistical analysis was carried out to examine the significance of differences in students' conceptual understanding resulting from the inquiry-based instructional intervention. The results of the assumption tests and hypothesis testing are presented in the following section.

A normality test is performed to determine whether the data obtained comes from a normally distributed population. The pretest and posttest scores were tested for normality using the Lilliefors test. The following table shows the results of the normality test:

Tabel 4. Pretest Posttest Normality Test Results

Score Data	N	A	l_{count}	l_{table}	Conclusion
Pretest	40	0,05	0,1241	0,1401	H_0 Accepted
Postest	40	0,05	0,1230	0,1401	H_0 Accepted

From the table above, in the pretest, Lo = 0.1241 was obtained, while Lt = 0.1401 with a significance level of α = 0.05 and n = 40, because Lhitung <Ltabel then Ho is accepted, namely the population is normally distributed. While in the posttest, Lo = 0.1230 was obtained, while Lt = 0.1401 with a significance level of α = 0.05 and n = 40, because Lhitung <Ltabel then Ho is accepted, namely the population is normally distributed.

The homogeneity test is conducted to determine whether the data obtained comes from a homogeneous population or not. The criteria for the homogeneity test are that Ho is accepted if the calculated F is smaller than the F table and Ho is rejected if the calculated F is greater than the F table. If Ho is accepted, it means the research data comes from a homogeneous population, while if Ho is rejected, it means the research data comes from a non-homogeneous population. On the pretest and posttest data, a homogeneity test was conducted using the Fisher exact test. The following table shows the results of the homogeneity test calculation:

Table 5. Results of Homogeneity Testing with Fisher's Exact Test

α	Value Data	Amount	Varians	F_{count}	F_{table}	Conclusion
0,05	Pretes	$N_{pretest}$= 40	27,97	1,56	1,69	H_0 Accepted
	Postest	$N_{postest}$= 40	43,76			

From the test results obtained the F_count value = 1.56 while the F_table value at the significance level α = 0.05, with the numerator degree of freedom 40 and the denominator degree of freedom 40 is 1.69. because the Fcount value is smaller than the F_table value, then Ho is accepted, so it can be concluded that both data are homogeneous. Based on the assumption tests that have been carried out, namely normality and homogeneity, it was found that so it was continued to the N-Gain test and T test.

Learning outcomes can be analyzed to see the extent to which inquiry-based chemistry learning influences the understanding of the concept of colloids. Improvements in student learning outcomes are obtained by comparing the results of the initial test with the final test and the test using the N-Gain value.

Tabel 6. Student N-Gain Results

	Pretest	Postest	Gain	Category
Average	50,45	72,75	0,46	Low

Based on the table above, it can be seen that there are 2 students (5%) in the high category, 37 students (97.5%) in the medium category, and 1 student (2.5%) in the low category. The following is a diagram of the categorization of N-gain scores.

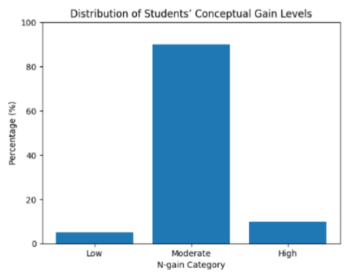

Figure 1. Percentage Diagram of N-Gain Score Categorization

The distribution of students' conceptual gain levels further illustrates the effectiveness of inquiry-based chemistry learning. As shown in Figure X, the majority of students achieved a moderate level of conceptual gain, indicating that inquiry-based instruction contributed to meaningful improvements in students' understanding of colloidal systems. Only a small proportion of students fell into the low and high gain categories, suggesting that while most learners benefited from the intervention, the extent of improvement varied across individuals.

The predominance of moderate gains aligns with the results of the N-gain analysis and reflects the role of guided inquiry in supporting conceptual development without overwhelming learners. These findings suggest that the instructional approach was effective in facilitating conceptual growth for most students, although additional instructional support may be required to promote higher levels of conceptual gain among a broader range of learners.

Hypothesis testing was conducted to determine the effect of inquiry-based chemistry learning on students' conceptual understanding. Hypothesis testing in this study used the "t" test. The t-test criteria are Ha is accepted if the calculated t is greater than the t table and Ha is rejected if the calculated t is smaller than the t table. If Ha is accepted, it means there is an effect of inquiry-based chemistry learning on students' conceptual understanding, while if Ha is rejected, it means there is no effect of inquiry-based chemistry learning on students' conceptual understanding. On the pretest and posttest scores, hypothesis testing was carried out using the t test. The following is a table of the results of the t test calculation:

Table 7. Results of Hypothesis Testing with the t-Test

N	α	t_{count}	F_{table}	Conclusion
40	0,01	4,84	2,68	H_a accepted

The results presented in Table 7 indicate a statistically significant difference in students' conceptual understanding before and after the implementation of inquiry-based chemistry learning. The obtained *t* value ($t_{(count)}$ = 4.84) exceeds the critical *t* value ($t_{(table)}$ = 2.68) at a significance level of α = 0.01. This finding leads to the acceptance of the alternative hypothesis (H_a), confirming that inquiry-based instruction had a significant effect on students' conceptual understanding of colloidal systems. These results provide strong statistical evidence that the observed improvement in students' posttest scores was not due to random variation but was attributable to the instructional intervention. The acceptance of H_a reinforces the effectiveness of inquiry-based learning as an instructional approach for enhancing conceptual understanding in secondary chemistry education.

The findings of this study demonstrate that inquiry-based chemistry learning plays a crucial role in facilitating students' conceptual development by actively engaging them in the process of knowledge construction. Rather than receiving information passively, students were encouraged to explore phenomena, formulate explanations, and justify their reasoning through experimental evidence. This active engagement aligns with constructivist learning theory, which emphasizes that meaningful learning occurs when learners integrate new experiences with prior knowledge. The overall improvement in students' conceptual understanding suggests that inquiry-based instruction supports deeper cognitive processing and promotes more coherent mental models of chemical concepts.

The variation in conceptual development across different indicators highlights the nuanced nature of learning in chemistry. Concepts grounded in observable phenomena and everyday contexts, such as the classification and applications of colloids, were more readily internalized by students. This suggests that inquiry-based learning is particularly effective when students can directly relate experimental observations to familiar real-world situations. Contextualized inquiry activities appear to reduce cognitive load and facilitate the formation of conceptual links between theory and practice, thereby strengthening students' understanding.

However, the persistence of misconceptions in certain conceptual domains indicates that inquiry-based learning alone may not be sufficient to address all learning challenges. Concepts that require integration across macroscopic, submicroscopic, and symbolic levels—such as colloidal properties—remain difficult for many students [44], [45]. This finding is consistent with existing literature in chemistry education, which reports that students often struggle with abstract representations and particle-level reasoning. These challenges underscore the importance of incorporating explicit scaffolding strategies within inquiry-based instruction to support students in navigating complex conceptual structures.

The diagnostic questionnaire results further emphasize the role of hands-on experimentation in supporting conceptual understanding. Students demonstrated strong conceptual interpretations when learning activities involved direct observation and experimentation, particularly in understanding phenomena such as light scattering and coagulation. These experiences allowed students to reconcile theoretical explanations with tangible evidence, thereby reinforcing conceptual clarity. Nevertheless, misconceptions related to classification and less explicitly demonstrated processes reveal the need for targeted instructional interventions that explicitly address conceptual boundaries and distinctions.

From a pedagogical perspective, the predominance of moderate conceptual gains suggests that guided inquiry offers a balanced instructional approach that supports learning without overwhelming students [46], [47]. While inquiry-based learning fosters engagement and conceptual growth, achieving higher levels of conceptual gain may require extended instructional time, repeated exposure to inquiry cycles, and differentiated scaffolding tailored to students' prior knowledge and learning needs. This highlights the importance of designing inquiry activities that are both cognitively challenging and adequately supported.

Overall, the results of this study contribute to the growing body of international research demonstrating the effectiveness of inquiry-based learning in chemistry education. By combining inquiry-based instruction with validated diagnostic assessment tools, this study provides insight into not only the extent of students' conceptual improvement but also the nature of their remaining misconceptions [48], [49]. These findings have important implications for chemistry educators seeking to design instructional strategies that promote meaningful conceptual understanding and long-term knowledge retention.

The findings of this study have several important implications for chemical education practice and research. The improvement in students' conceptual understanding through inquiry-based learning indicates that instructional approaches emphasizing active exploration, questioning, and evidence-based reasoning can effectively support students in constructing meaningful chemical concepts, particularly for abstract topics such as colloidal systems [33], [50]. These results suggest that chemistry teachers should consider integrating structured inquiry activities into regular classroom instruction to facilitate deeper engagement with chemical representations at macroscopic, submicroscopic, and symbolic levels. Furthermore, the use of diagnostic assessments provides valuable insights into students' learning processes and misconceptions, which can inform more targeted instructional interventions and curriculum refinement in secondary chemistry education.

Despite these contributions, this study is subject to several limitations that should be considered when interpreting the results. First, the research was conducted in a single school context with a limited sample size, which may restrict the generalizability of the findings to broader educational settings. Second, the duration of the intervention was relatively short, limiting the ability to examine long-term retention of conceptual understanding. Third, the study focused primarily on conceptual outcomes without incorporating qualitative data such as classroom observations or student interviews that could further illuminate students' learning experiences. Future research is therefore recommended to involve larger and more diverse samples, extend the duration of inquiry-based interventions, and employ mixed-methods approaches to provide a more comprehensive understanding of the impact of inquiry-based learning on students' conceptual development in chemistry.

4. CONCLUSION

Based on the data analysis, it can be concluded that inquiry-based chemistry learning has a significant positive effect on students' conceptual understanding of colloidal systems. The findings indicate that students who engaged in inquiry-oriented instructional activities demonstrated meaningful conceptual improvement compared to their initial understanding. These results provide empirical support for the effectiveness of inquiry-based learning as an instructional approach for promoting deeper conceptual understanding in secondary chemistry education. Future research is recommended to investigate the long-term effects of inquiry-based learning on students' conceptual retention and transfer across different chemistry topics and educational contexts. In addition, subsequent studies should employ mixed-methods designs involving larger and more diverse samples to explore how students' reasoning processes and misconceptions evolve during inquiry-based chemistry instruction.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the school administrators, chemistry teachers, and students who participated in this study for their cooperation and support. Appreciation is also extended to colleagues and reviewers who provided valuable feedback and constructive suggestions that contributed to the improvement of this manuscript.

REFERENCES

[1] S. O. Makinde and N. O. Oyeniyi, "The Roles of Emerging Technology in Chemistry Teaching and Learning for a Sustainable Development," *Indones. J. Teach. Sci.*, vol. 4, no. 2, pp. 177–188, 2024, doi: 10.17509/ijotis.v4i2.75554.
[2] A. Ncube, S. Mtetwa, M. Bukhari, G. Fiorentino, and R. Passaro, "Circular Economy and Green Chemistry: The Need for Radical Innovative Approaches in the Design for New Products," *Energies*, vol. 16, no. 4, p. 1752, Feb. 2023, doi: 10.3390/en16041752.
[3] M. A. L. Blackie, "Knowledge building in chemistry education," *Found. Chem.*, vol. 24, no. 1, pp. 97–111, Apr. 2022, doi: 10.1007/s10698-022-09419-w.
[4] G. Jiménez-Valverde, "Narrative Approaches in Science Education: From Conceptual Understanding to Applications in Chemistry and Gamification," *Encyclopedia*, vol. 5, no. 3, p. 116, Aug. 2025, doi: 10.3390/encyclopedia5030116.
[5] G. Renvall and B. Kurtén, "Talking Chemistry in Small Groups: Challenges with Macroscopic, Submicroscopicand Symbolic Representations Among Students," *FMSERA J.*, vol. 6, no. 2, p. 58, 2024.
[6] H. O. Kapici, "From Symbolic Representation to Submicroscopic One: Preservice Science Teachers' Struggle with

Chemical Representation Levels in Chemistry," *Int. J. Res. Educ. Sci.*, vol. 9, no. 1, pp. 134–147, 2023, doi: 10.46328/ijres.3122.
[7] T. Fatacharmita, T. Hadinugrahaningsih, and I. Irwanto, "Analysis of Students' Conceptual Understanding on Colloidal Materials Through the Flipped Classroom Learning Model Integrated Peer-Instruction," *J. Comput. Sci. Math. Learn.*, vol. 1, no. 2, pp. 79–92, Aug. 2024, doi: 10.70232/thnvb502.
[8] H. Retnawati *et al.*, "The influence of the application of mathematics on students' difficulties in solving chemical problems: A longitudinal study using national examination data," *EPJ Web Conf.*, vol. 344, p. 01009, Dec. 2025, doi: 10.1051/epjconf/202534401009.
[9] S. Winarni and S. Syahrial, "Revealing Chemical Misconceptions Through The Microteaching Process in The Era of The Covid-19 Pandemic," *JKPK (Jurnal Kim. dan Pendidik. Kim.*, vol. 7, no. 1, p. 50, 2022, doi: 10.20961/jkpk.v7i1.55587.
[10] K. Widiastari and I. W. Redhana, "Multiple representation-based chemistry learning textbook of colloid topic," *J. Phys. Conf. Ser.*, vol. 1806, no. 1, p. 012185, Mar. 2021, doi: 10.1088/1742-6596/1806/1/012185.
[11] N. N. S. P. Verawati and N. Nisrina, "Reimagining Physics Education: Addressing Student Engagement, Curriculum Reform, and Technology Integration for Learning," *Int. J. Ethnoscience Technol. Educ.*, vol. 2, no. 1, pp. 158–181, Mar. 2025, doi: 10.33394/ijete.v2i1.14058.
[12] K. Kalita and M. Nath, "A Comparative Analysis of Different Teaching Methods on Student Achievement in Mathematics," *Shodhshauryam, Int. Sci. Ref. Res. J.*, vol. 8, no. 4, pp. 100–117, 2025.
[13] A. H. Mir, "Learner-Centered Pedagogies: Transforming Education for the 21St Century," *J. Account. Res. Util. Financ. Digit. Assets*, vol. 3, no. 4, pp. 383–387, 2025, [Online]. Available: https://doi.org/10.54443/jaruda.v3i4.217
[14] M. A. Alam, "From Teacher-Centered To Student-Centered Learning: The Role of Constructivism and Connectivism In Pedagogical Transformation," *CONFLUX J. Educ.*, vol. 11, no. 2, pp. 154–167, 2023, [Online]. Available: https://cjoe.naspublishers.com
[15] M. B. Thomas, A. Muscat, A. Zuccolo, C. N. Luguetti, and A. Watt, "Navigating Pedagogical Innovation in Higher Education: Education Academics'Experiences with Active and Inquiry-Based Learning in Intensive Teaching," *Innov. High. Educ.*, vol. 50, no. 6, pp. 1917–1943, Dec. 2025, doi: 10.1007/s10755-025-09807-y.
[16] J. Saheli, "Analysing Constructivist Teaching Approaches to Support Cognitive and Emotional Needs in Mentally Ill Learners," *Bharati Int. J. Multidiscip. Res. Dev.*, no. July, pp. 277–285, 2025.
[17] R. Safkolam, S. Madahae, and P. Saleah, "The Effects of Inquiry-based Learning Activities to Understand the Nature of Science of Science Student Teachers," *Int. J. Instr.*, vol. 17, no. 1, pp. 479–496, 2024, doi: 10.29333/iji.2024.17125a.
[18] M. Vilela, C. Morais, and J. C. Paiva, "Inquiry-Based Science Education in High Chemistry: Enhancing Oral and Written Communication Skills Through Authentic and Problem-Based Learning Activities," *Educ. Sci.*, vol. 15, no. 334, pp. 1–18, 2025, doi: 10.3390/educsci15030334.
[19] M. J. Gomez, "The Impact of Inquiry-Based Learning in Science Education: A Systematic Review of Student Engagement and Achievement," *J. Educ. Learn. Manag.*, vol. 2, no. 2, pp. 353–363, Nov. 2025, doi: 10.69739/jelm.v2i2.1143.
[20] N. Mediana, A. Funa, and R. Dio, "Effectiveness of Inquiry-based Learning (IbL) on Improving Students' Conceptual Understanding in Science and Mathematics: A Meta-Analysis," *Int. J. Educ. Math. Sci. Technol.*, vol. 13, no. 2, pp. 532–552, 2025, doi: 10.46328/ijemst.4769.
[21] D. L. Morris, "Rethinking Science Education Practices: Shifting from Investigation-Centric to Comprehensive Inquiry-Based Instruction," *Educ. Sci.*, vol. 15, no. 1, pp. 1–18, 2025, doi: 10.3390/educsci15010073.
[22] D. L. Morris, "Rethinking Science Education Practices: Shifting from Investigation-Centric to Comprehensive Inquiry-Based Instruction," *Educ. Sci.*, vol. 15, no. 1, p. 73, Jan. 2025, doi: 10.3390/educsci15010073.
[23] T. Hagos and D. Andargie, "Effects of technology-integrated formative assessment on students' conceptual and procedural knowledge in chemical equilibrium," *J. Educ. Learn.*, vol. 17, no. 1, pp. 113–126, 2023, doi: 10.11591/edulearn.v17i1.20630.
[24] A. A. Espinosa, D. Koperová, M. Kuhnová, and M. Rusek, "Preservice Chemistry Teachers' Conceptual Understanding and Confidence Judgment: Insights from a Three-Tier Chemistry Concept Inventory," *J. Chem. Educ.*, vol. 102, no. 1, pp. 53–65, Jan. 2025, doi: 10.1021/acs.jchemed.4c01146.
[25] M. Ncube and K. Luneta, "Concept-based instruction: Improving learner performance in mathematics through conceptual understanding," *Pythagoras*, vol. 46, no. 1, Apr. 2025, doi: 10.4102/pythagoras.v46i1.815.
[26] E. Khasawneh, A. Hodge-Zickerman, C. S. York, T. J. Smith, and H. Mayall, "Examining the effect of inquiry-based learning versus traditional lecture-based learning on students' achievement in college algebra," *Int. Electron. J. Math. Educ.*, vol. 18, no. 1, p. em0724, Jan. 2023, doi: 10.29333/iejme/12715.
[27] M. N. Sarwar *et al.*, "Concept mapping and conceptual change texts: a constructivist approach to address the misconceptions in nanoscale science and technology," *Front. Educ.*, vol. 9, Feb. 2024, doi: 10.3389/feduc.2024.1339957.
[28] E. A. Datingaling, "Correlates of Listening Comprehension Towards the Development of An Assessment Tool," *Aloysian Interdiscip. J. Soc. Sci. Educ. Allied Fields*, vol. 1, no. 10, pp. 18–39, 2025, doi: 10.5281/zenodo.17422492.
[29] K. M. Jegstad, "Inquiry-based chemistry education: a systematic review," *Stud. Sci. Educ.*, vol. 60, no. 2, pp. 251–313, Jul. 2024, doi: 10.1080/03057267.2023.2248436.
[30] T. Farxod, Sabina, Pardayev, "Inquiry-Based Learning in Chemistry Education Exploring its Effectiveness.pdf," *Integr. Sci. Educ.*, vol. 1, no. 3, pp. 74–79, 2024, [Online]. Available: http://journal.uzfi.uz/index.php/ISE/article/view/99%0Ahttp://journal.uzfi.uz/index.php/ISE/article/download/99/174
[31] A. Alya and K. Dwiningsih, "Project-Based Interactive Colloidal E-Module in Chemistry Learning to Improve Student's Science Process Skills and Understanding Concepts," *Form. J. Ilm. Pendidik. MIPA*, vol. 14, no. 1, Mar. 2024, doi: 10.30998/formatif.v14i1.17934.
[32] F. Hanum, A. Sebayang, F. Fitriati, E. Tarigan, and L. Tarigan, "Implementing an Inquiry-Based Learning Model to Deepen Students' Conceptual Understanding," *J. La Edusci*, vol. 6, no. 5, pp. 946–960, Nov. 2025, doi:

10.37899/journallaedusci.v6i5.2645.
[33] M. Anwar, “Evaluating the Impact of Inquiry-Based Teaching Strategies on the Development of Scientific Thinking, Problem-Solving, and Conceptual Understanding Among High School Students,” *J. Soc. Horizons*, vol. 1, no. 2, pp. 01–10, 2024.
[34] M. A. M. Gabr, W. F. Sleem, and N. S. El-wkeel, “Effect of virtual reality educational program on critical thinking disposition among nursing students in Egypt: a quasi-experimental pretest–posttest design,” *BMC Nurs.*, vol. 24, no. 1, p. 874, Jul. 2025, doi: 10.1186/s12912-025-03488-w.
[35] I. Amalia, D. Solihat, and E. Darsih, “the Effect of Kahoot Application in Improving Students’ Wirting Skill,” *Indones. J. Learn. Instr.*, vol. 5, no. 1, pp. 23–30, 2022, doi: 10.25134/ijli.v5i1.5873.Received.
[36] Ç. Şenyiğit, F. Önder, and İ. Sılay, “An Inquiry-Based Learning Approach for Effective Concept Teaching,” *I.E. Inq. Educ.*, vol. 13, no. 1, pp. 1–24, 2021, [Online]. Available: https://digitalcommons.nl.edu/ie/vol13/iss1/10/
[37] A.-I. Zourmpakis, M. Kalogiannakis, and S. Papadakis, “The Effects of Adaptive Gamification in Science Learning: A Comparison Between Traditional Inquiry-Based Learning and Gender Differences,” *Computers*, vol. 13, no. 12, p. 324, Dec. 2024, doi: 10.3390/computers13120324.
[38] S. R. Windani, E. Susilaningsih, W. Sumarni, and S. Haryani, “Development of a Scientific Literacy Test Instrument to Identify Students’ Understanding of Concepts and Misconceptions in Colloidal Systems Material,” *Chemined*, vol. 13, no. 1, pp. 10–19, 2024, doi: 10.1111/j.1949-8594.1902.tb00418.x.
[39] I. Rezkia Lukman, M. Mellyzar, S. Alvina, and N. Saa’dah, “Development of a Chemical Literacy Assessment on Colloid (CLAC) Instrument to Measure Chemical Literacy,” *Proc. Malikussaleh Int. Conf. Multidiscip. Stud.*, vol. 3, pp. 88–95, Dec. 2022, doi: 10.29103/micoms.v3i.50.
[40] N. Mariliaty and T. Suhery, “Optimization of basic chemistry learning: Validation of stem-based problem-based learning materials for chemical equilibrium,” *Asian J. Collab. Soc. Environ. Educ.*, vol. 2, no. 1, pp. 30–45, Jul. 2024, doi: 10.61511/ajcsee.v2i1.2024.909.
[41] T. Abate and E. Mishore, “Alignment analysis between teacher-made tests with the learning objectives in a selected school of central regional state of Ethiopia,” *Heliyon*, vol. 10, no. 11, pp. 1–14, 2024, doi: 10.1016/j.heliyon.2024.e31869.
[42] C. M. Vrbin, “Parametric or nonparametric statistical tests: Considerations when choosing the most appropriate option for your data,” *Cytopathology*, vol. 33, no. 6, pp. 663–667, Nov. 2022, doi: 10.1111/cyt.13174.
[43] C. E. Agbangba, E. Sacla Aide, H. Honfo, and R. Glèlè Kakai, “On the use of post-hoc tests in environmental and biological sciences: A critical review,” *Heliyon*, vol. 10, no. 3, pp. 1–12, 2024, doi: 10.1016/j.heliyon.2024.e25131.
[44] J. Laohapornchaiphan and P. Chenprakhon, “A Review of Research on Learning Activities Addressing the Submicroscopic Level in Chemistry,” *J. Chem. Educ.*, vol. 101, no. 11, pp. 4552–4565, Nov. 2024, doi: 10.1021/acs.jchemed.4c00156.
[45] P. D. Anugrahani, K. K. Destafia, R. Alicia, F. Sairil, U. Khoiriyah, and M. A. Arivi, “Development of Articulate Storyline Interactive Media on Colloid Material to Improve Students ’ Visual Abilities,” *JIPI (Jurnal IPA dan Pembelajaran IPA)*, vol. 9, no. 4, pp. 1185–1203, 2025.
[46] V. H. Nguyen, R. Halpin, and A. R. Joy-Thomas, “Guided inquiry-based learning to enhance student engagement, confidence, and learning,” *J. Dent. Educ.*, vol. 88, no. 8, pp. 1040–1047, Aug. 2024, doi: 10.1002/jdd.13531.
[47] Z. Ayık and M. D. Gül, “Teacher Support Adaptivity in Physics Classroom for Gifted Students,” *J. Pendidik. Fis. Indones.*, vol. 21, no. 1, pp. 19–31, Jun. 2025, doi: 10.15294/jpfi.v21i1.14437.
[48] J. Siantuba, L. Nkhata, and T. de Jong, “The impact of an online inquiry-based learning environment addressing misconceptions on students’ performance,” *Smart Learn. Environ.*, vol. 10, no. 1, pp. 1–18, 2023, doi: 10.1186/s40561-023-00236-y.
[49] T. El Fathi, A. Saad, H. Larhzil, D. Lamri, and E. M. Al Ibrahmi, “Integrating generative AI into STEM education: enhancing conceptual understanding, addressing misconceptions, and assessing student acceptance,” *Discip. Interdiscip. Sci. Educ. Res.*, vol. 7, no. 1, pp. 1–21, 2025, doi: 10.1186/s43031-025-00125-z.
[50] E. G. A. Tolba and A. M. Al-Osaimi, “The effectiveness of using the model-based thinking strategy in developing first-grade high school students’ physical concepts and inquiry thinking skills,” *Eurasia J. Math. Sci. Technol. Educ.*, vol. 19, no. 4, p. em2254, Apr. 2023, doi: 10.29333/ejmste/13111.