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STEM-BASED GUIDED INQUIRY IN COLLOID PRACTICUMS AND ITS INFLUENCE ON STUDENTS' CONCEPT MASTERY

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ABSTRACT

The rapid development of science and technology in the 21st century necessitates an educational approach that fosters students' critical thinking, problem-solving, and conceptual mastery skills, particularly in complex topics such as colloids. This study aims to examine the effectiveness of applying a STEM-based guided inquiry approach in colloid practicums on improving students' conceptual mastery. The research design used was a quasi-experimental pretest-posttest control group study involving 34 second-semester students in the Chemistry Education Program at UIN Ar-Raniry. The research instruments consisted of a two-level multiple-choice concept mastery test and a STEM learning effectiveness questionnaire. The study was conducted over six weeks through several colloid laboratory sessions. Statistical analysis using ANCOVA ($p < 0.005$) showed a significant difference in posttest scores between the experimental and control groups. The high effect size (Cohen's $d = 0.8$) indicates that this approach has a significant impact on student learning outcomes, particularly in developing higher-order thinking skills at levels C4 to C6. This study indicates that integrating a contextual, student-centered STEM-based learning model into chemistry laboratory sessions can enhance conceptual understanding and 21st-century skills. However, limitations such as a small sample size, research location restricted to a single institution, and relatively short treatment duration should be considered when generalizing the study's findings. Further research with a longitudinal design and a broader sample scope is highly recommended.

INTRODUCTION

The development of technology in the digital era has brought about a major transformation in the world of education. The 21st-century education system is required not only to transfer knowledge but also to equip learners with critical, creative, collaborative, and adaptive thinking skills to face dynamic global challenges (Stanislaw, 2022; Abdurrahman et al., 2023). In this context, learning innovation is important to support the achievement of Sustainable Development Goals (SDGs), especially Goal 4 (quality education) and Goal 9 (education innovation and infrastructure), which emphasize the importance of learning approaches that are relevant to the needs of the times and based on strengthening 21st century skills (Rahmawati et al., 2022; Sari et al., 2025).

Chemistry, as part of basic science, makes a significant contribution to life, particularly in the fields of environment, industry, and health. However, in practice, chemistry is often considered a challenging subject to comprehend because it encompasses abstract concepts, particularly those related to microscopic and invisible materials (Akkoyun et al., 2023; Oladejo et al., 2023). One of the most challenging materials is colloids,

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which are heterogeneous mixtures with unique characteristics between solutions and suspensions (La Mesa & Risuleo, 2021).

The results of a preliminary study of 2nd-semester students in the Chemistry Education Study Program showed that more than 60% of students had difficulty understanding the concept of colloids, particularly in distinguishing between the types of colloids and explaining their properties conceptually. Interviews with laboratory instructors also revealed that the conventional approach currently used has not accommodated the learning needs that develop high-level thinking skills. This finding aligns with Rusmansyah et al. (2023), who reported that only 42.8% of high school students scored above the passing grade for this material. Furthermore, many students were not able to identify the types and properties of colloids correctly (Fitriyana et al., 2024).

In response to these challenges, Science, Technology, Engineering, and Mathematics (STEM)-based learning combined with a guided inquiry approach is a strategic alternative. This approach encourages students to be actively involved in structured scientific investigations, progressing through the stages of orientation, problem identification, data collection, analysis, and conclusion (Price et al., 2021; Saputro & Prastowo, 2022). This process is believed to improve conceptual understanding, higher-order thinking skills (HOTS), and learning motivation (Dew et al., 2024; Slapničar et al., 2024). Furthermore, STEM-based laboratory experiments can enrich the learning experience by integrating theory and practice, and provide a more comprehensive and relevant understanding of chemistry concepts (Luo et al., 2023; Halawa et al., 2024; Pohan, 2024).

Previous studies have discussed the effectiveness of inquiry-based or STEM approaches in chemistry education. For example, Kusasi and Najmiati (2021) showed that STEM-based guided inquiry learning can improve students' scientific literacy on the topic of static fluids. Babalola and Keku (2024) found that project-based learning, combined with an ethno-STEM approach, enhances students' critical and creative thinking skills. Huri and Karpudewan (2019) found that integrating STEM into laboratory work can improve students' conceptual understanding and critical thinking skills. Herianto et al. (2024) demonstrated that guided inquiry can enhance students' active engagement in learning and facilitate their development of a deeper understanding of scientific concepts.

Although numerous studies have examined STEM-based guided inquiry, these studies primarily focus on the effectiveness of STEM. Additionally, previous STEM studies have been conducted primarily at the high school level. Research integrating the STEM approach and guided inquiry in the context of chemistry practicums, particularly on abstract and applied colloid material, has not been found in the literature. Therefore, this study aims to answer the following questions:

1. Can a guided inquiry-based STEM approach improve students' conceptual understanding of colloid material?
2. Are there any changes in students' higher-order thinking skills (HOTS) after participating in STEM-Inquiry learning?

METHODS

This study employed a quantitative approach with a pretest-posttest control group quasi-experimental design (Reichardt, 2019). The research was conducted in three stages. First, a pretest was administered to both groups to determine the students' initial abilities. Second, the experimental group was taught using a guided inquiry approach based on STEM, while the control group followed conventional learning using the lecture method. Third, a posttest was administered to both groups to measure the increase in concept mastery after learning. The research design is presented in Table 1.

Table 1. Pretest-Posttest Control Group Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X_1	O_2
Control	O_1	X_2	O_2

Description:
O_1: Pretest of experimental and control groups;
O_2: Posttest of experimental and control groups;
X_1: STEM-based guided inquiry as the treatment;
X_2: Conventional learning with lecture.

This research was conducted at Ar-Raniry State Islamic University in Banda Aceh for six weeks. The population in this study consisted of all second-semester students in the Chemistry Education Study Program who were enrolled in Basic Chemistry courses. The sampling technique used was total sampling, which included all students in the population, totaling 34 individuals.

The independent variable in this study was the implementation of STEM-based guided inquiry learning, while the dependent variable was mastery of colloid concepts. Additionally, pretest scores were used as covariates to control for the influence of students' initial abilities on their posttest results.

The primary instrument in this study was a two-tier, multiple-choice test consisting of 12 questions. The two-tier diagnostic test model was chosen because this instrument has been proven effective in comprehensively detecting students' conceptual understanding and misconceptions. This approach enables the revelation of patterns of thinking among students that cannot be accessed by conventional multiple-choice questions (Lukum et al., 2023; Mardiyyaningsih et al., 2023). These questions were developed based on basic competencies and learning outcomes related to colloid materials in Basic Chemistry courses. They were designed to measure students' higher-order thinking skills at cognitive levels C4 (analyzing), C5 (evaluating), and C6 (creating), in accordance with Bloom's revised taxonomy.

Each question consists of two levels: (Tier 1) conventional multiple-choice questions that test students' conceptual understanding of colloid-related chemical phenomena or principles. (Tier 2) reasoned questions that ask students to explain or provide scientific justification for the answers chosen in Tier 1.

To provide a more comprehensive assessment in line with the constructivist pedagogical approach, assessment indicators were used to evaluate a combination of students' answers and reasoning, as shown in Table 2.

Table 2. Assessment Indicators for Tiered Questions

Score	Assessment Criteria
4	Tier 1 is correct, and Tier 2 is correct with scientific reasoning and in accordance with theory.
3	Tier 1 is correct, but Tier 2 is only partially correct or with general/non-conceptual reasoning.
2	Tier 1 is incorrect, but Tier 2 demonstrates logical understanding even though it is inaccurate.
1	Tier 1 is incorrect, and Tier 2 is completely incorrect or contains misconceptions.
0	No answer/answer completely irrelevant.

(Lestari et al., 2023)

The content validity of the instrument was assessed using the Aiken index, and its reliability was evaluated using the Cronbach's alpha formula, yielding a coefficient of 0.758, indicating that the instrument is reliable. Additionally, the quality of each item was reviewed based on its discriminative power and level of difficulty.

Data were collected through a pretest and posttest using a concept mastery test instrument. Additionally, a STEM questionnaire was used to assess the effectiveness of STEM practical learning. Data analysis was performed using SPSS software version 26. The initial step of the analysis involved a normality test using the Kolmogorov-Smirnov test and a homogeneity test using Levene's Test to ensure that the data met the parametric assumptions. Next, a covariate analysis (ANCOVA) was conducted to determine the significant effect of the treatment on posttest scores after controlling for pretest scores (Stanley, 2022)

To complement the analysis of treatment effectiveness in practical terms, effect size calculations were performed using Cohen's d. This effect size aims to show the magnitude of the treatment's influence on student learning outcomes. The interpretation of Cohen's d values refers to general criteria: 0.2 for small effects, 0.5 for moderate effects, and 0.8 for large effects (Cohen, 2013).

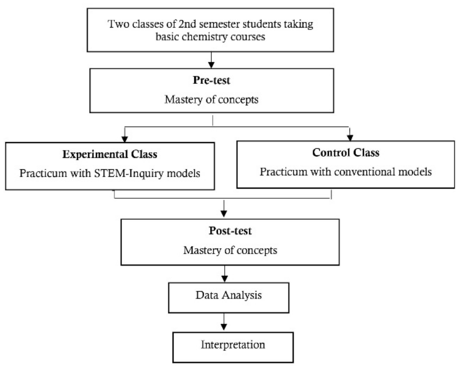

Figure 1. Research Design (experimental research with one group pretest-posttest)

RESULTS AND DISCUSSION

This study examines the effectiveness of guided inquiry learning based on STEM (Science, Technology, Engineering, and Mathematics) on students' mastery of the concept of colloids. Using a two-tier multiple-choice test instrument consisting of 12 questions at levels C4-C6, this study measures students' high-level thinking skills before and after treatment. The results of the pretest of students' concept mastery of colloids are presented in Figure 2.

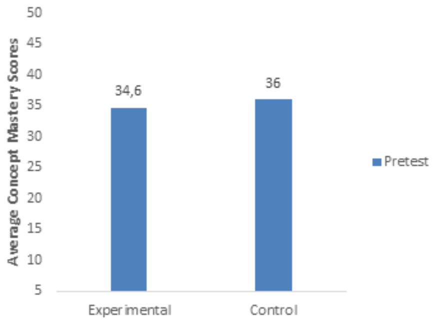

Figure 2. Average Pretest Scores of Students' Concept Mastery

Figure 2 shows that the average score of students in the experimental class was 34.8, while in the control class, it was 36. This relatively small difference indicates that the initial abilities of students in both groups are similar.

Tests were conducted using SPSS 26 for Windows to validate this similarity. First, a normality test was conducted to ensure the data distribution was normal. The results showed that the data in both classes were normally distributed, with a significance value of 0.548 < 0.05 for the experimental group and 0.677 < 0.05 for the control group. Furthermore, a homogeneity test was conducted to check the uniformity of data variance. The analysis produced a significance value of 0.834 > 0.05, confirming that the pretest data were homogeneous. After meeting the prerequisites for normality and homogeneity, an independent t-test was conducted to determine whether the two average scores were equal. The results of this test produced a significance value of 0.803, which is greater than 0.05. This finding statistically proves no significant difference in the concept mastery of colloids in the experimental and control groups.

After the pretest, the study proceeded to the implementation stage, where different treatments were applied to both groups. The experimental group received treatment through STEM-based guided inquiry in learning and practicum. Meanwhile, the control group learned with a conventional lecture model. After the learning, both groups were given a posttest to measure the increase in colloid concept mastery. The posttest results from both groups are presented in Figure 3.

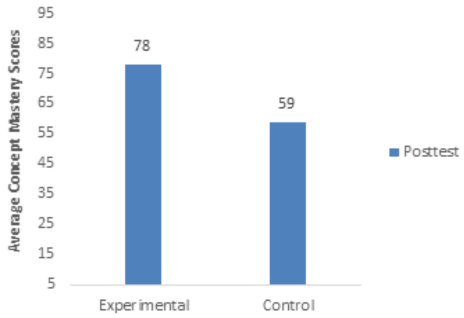

Figure 3. Average Scores of Students' Concept Mastery of Colloids

Data analysis in Figure 3 reveals a significant difference in the achievement of critical thinking skills between the experimental and control groups after treatment. Students in the experimental group who received STEM-based guided inquiry learning showed a higher increase, with an average score of 78. On the other hand, the control group, which followed the conventional learning method, obtained a lower average score of 59. The 19-point difference indicates a more significant positive impact of STEM-based guided inquiry on developing students' thinking skills in the context of mastering the colloid concept. This finding aligns with Komalasari et al. (2024), who found that STEM learning, combined with a scientific approach, has a simultaneous effect on critical thinking skills and learning outcomes. Then, Pitiporntapin et al. (2024) state that project-based and contextualized learning is very effective in strengthening students' conceptual understanding and cross-disciplinary skills.

To obtain more accurate results and consider the students' initial abilities, an ANCOVA (Analysis of Covariance) analysis was conducted with pretest scores as covariates. The analysis results showed a significant value (0.000 < 0.05), indicating that the learning treatment had a significant effect on learning outcomes, even after controlling for students' initial abilities. According to Owolade et al. (2022), the learning model has a significant impact on students' inquiry skills. This finding supports Chaerunisa et al. (2023), who found that effective learning strategies improve students' academic performance.

Furthermore, to measure the magnitude of the effect (effect size) of the instructional treatment, calculations were performed using Cohen's d formula. The result yielded a Cohen's d value of 0.8, which falls into the large category. This suggests that the guided inquiry-based STEM approach has a significant impact on enhancing students' understanding of colloid concepts. This finding is reinforced by Ouahi et al. (2024), who found that experiential and simulation-based approaches are very effective in helping students understand abstract science material and encourage the development of critical thinking skills.

Through STEM-based projects and experiments, students are trained to analyze, evaluate, and create according to cognitive levels C4-C6 in Bloom's taxonomy. Students' concept mastery at each cognitive level is presented in Figure 4.

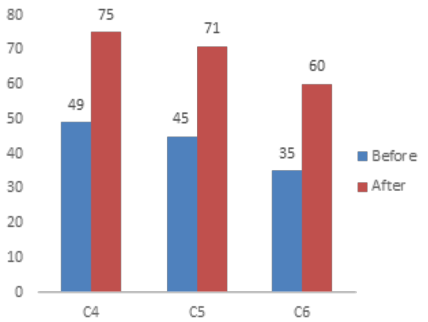

Figure 4. Distribution of Correct Answers at Each Question Level Before and After Implementing STEM-Based Guided Inquiry Learning

Based on Figure 4, there is an increase in the skills to analyze, synthesize, and evaluate before and after implementing STEM-based guided inquiry in colloid learning. This finding can be observed from the number of students' correct answers, which is more significant than before STEM-based learning. In line with the results of a meta-analysis showing that the implementation of STEM-based guided inquiry significantly contributes to improving higher-order thinking skills, science literacy, and student learning motivation (Adauyah & Aznam, 2024)

Furthermore, these findings support constructivist learning theory, particularly inquiry-based learning, which emphasizes active student involvement in building conceptual understanding through direct experience. According to Bruner (1961), inquiry enables students to discover knowledge through an exploratory process, which is reinforced in the context of STEM-based practicums. One relevant model is Bybee's (1997) 5E model, which consists of the stages of Engage, Explore, Explain, Elaborate, and Evaluate (Twizeyimana et al., 2024). In this study, a systematic guided inquiry was conducted, beginning with problem formulation, experimentation, and concept evaluation, which allowed students to experience the scientific process thoroughly. This approach not only developed a deeper understanding of concepts but also improved higher-order thinking skills such as analysis, evaluation, and synthesis, as reflected in the results of conceptual tests at cognitive levels C4 to C6 (Baharin et al., 2018; Erfianti et al., 2019; Keleman et al., 2021). Thus, the integration of guided inquiry and the STEM approach significantly contributes to achieving 21st-century learning.

The use of the STEM approach supports cross-disciplinary integration that can expand students' thinking frameworks from mere conceptual understanding to systemic and applied thinking skills (Mayes & Rittschof, 2021; Hakim et al., 2023). For example, in practical work on the creation of artificial colloidal systems (such as emulsions and sols), students not only observe physical and chemical changes, but also analyze the composition of materials (science), understand the processes involved in the equipment (technology), design procedures (engineering), and perform proportional calculations (mathematics). This creates an authentic learning experience as suggested in experiential learning theory, where students are directly involved in a cycle of experience-based learning, reflection, and application of scientific concepts (Gani, 2020; Dewanto et al., 2024).

The main novelty of this study lies not only in the integration of STEM and guided inquiry approaches but also in its implementation in the context of colloid practicums in higher education, which are designed based on exploratory, collaborative, and project-based principles. Previous studies have tended to examine the effectiveness of STEM (Hanif et al., 2019; Sumarni & Kadarwati, 2020) or guided inquiry (Cetin, 2021) separately, and have been mostly limited to primary and secondary education levels (Ozturk, 2021). The learning model developed in this study adapts six STEM principles into laboratory inquiry stages and is validated through a two-tier assessment to measure higher-order thinking skills (Kahar et al., 2022; Yuliati et al., 2020). This approach yields a transdisciplinary, practical framework that facilitates the transfer of knowledge from the laboratory to real-world contexts (Nasir et al., 2022; Ro et al., 2024). Thus, this study makes a concrete contribution in the form of an innovative, practical design that can be adopted in STEM-based chemistry laboratory curricula in higher education, particularly for abstract materials such as colloids.

Research by Salchegger et al. (2021), Alqawasmi et al. (2024), and Teplá and Distler (2025) also confirms that inquiry-based learning at the university level has a significant impact on student motivation and conceptual achievement, especially when designed collaboratively and project-based.

The practical implications of these findings are important for lecturers and curriculum designers. First, lecturers can apply the STEM-Inquiry learning model to increase student active participation and conceptual understanding. Practical modules should be redesigned to reflect interdisciplinary integration and accommodate the inquiry stages, including orientation, problem formulation, experimentation, data analysis, and evaluation. Second, curriculum designers can consider integrating the STEM-Inquiry approach as part of strengthening learning outcomes based on the KKNI (National Qualifications Framework) and OBE (Outcome-Based Education), particularly in foundational courses that require high analytical and synthesis skills.

CONCLUSION

This study demonstrates that the implementation of a STEM-based guided inquiry model in colloid practicums can significantly enhance students' conceptual understanding and higher-order thinking skills (C4–C6). The findings affirm the potential of this model to foster meaningful and active learning experiences in chemistry education at the higher education level. The core contribution of this research lies in offering a practical and systematic STEM-Inquiry framework for laboratory-based learning that integrates scientific investigation with 21st-century competencies, including collaboration, problem-solving, and cross-disciplinary thinking. This model addresses a notable gap in the literature, as few studies have applied STEM-guided inquiry in tertiary-level chemistry practicums, particularly on abstract topics such as colloids. These findings have practical implications for instructors who can redesign laboratory modules to incorporate inquiry phases and STEM integration, as well as for curriculum developers seeking to align learning strategies with the KKNI and OBE frameworks. Despite its promising outcomes, this study is limited by its small sample size, single-institution setting, and relatively short intervention period. Future research should consider multi-institutional collaborations, more extended implementation periods, and qualitative analyses to capture students' reflective experiences and conceptual growth. Expanding the scope to other chemistry topics or integrating digital tools, such as virtual labs or AI-based scaffolding, may further enrich the impact of STEM-inquiry learning models.

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