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Guided Discovery Learning for Acid-Base Chemistry: Effects on Student Achievement and Conceptual Mastery

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Article Info

ABSTRACT

Purpose of the study: This study aims to analyze the effect of guided discovery learning on students' chemistry learning outcomes and conceptual understanding in acid-base topics, addressing challenges in mastering abstract chemical concepts through structured experimental activities.

Methodology: A quasi-experimental design with a non-equivalent control group was employed. The experimental group received guided discovery learning integrated with laboratory activities, while the control group followed conventional instruction. Data were collected through pre-tests, post-tests, and observation sheets, and analyzed using descriptive statistics, independent sample t-tests, N-gain, and effect size (Cohen's d) with SPSS software.

Main Findings: Results show that the experimental group achieved higher post-test scores (Mean = 82.15, N-gain = 0.67) compared to the control group (Mean = 70.21, N-gain = 0.45), with a statistically significant difference (p = 0.001) and a large effect size (Cohen's d = 0.82). Guided discovery learning effectively improves students' conceptual understanding and overall chemistry learning outcomes.

Novelty/Originality of this study: This study integrates guided discovery learning with systematically designed laboratory activities in acid-base instruction, providing a holistic evaluation of learning improvement. The approach connects theoretical concepts with practical experiences, offering a more effective instructional model and contributing new knowledge for enhancing chemistry education practices in secondary schools.

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1. INTRODUCTION

Science education, particularly chemistry, plays a crucial role in fostering students' critical thinking and problem-solving skills in the 21st century. However, chemistry is often perceived as a difficult subject due to its abstract nature, especially in topics such as acids and bases that require understanding at macroscopic, microscopic, and symbolic levels [1]-[3]. This complexity frequently leads to low student achievement in chemistry learning across different educational levels [4]-[6]. Previous studies have indicated that traditional teacher-centered approaches still dominate classroom practices and fail to actively engage students in constructing their own knowledge [7]-[9]. Therefore, innovative instructional strategies are needed to enhance students' conceptual understanding and learning outcomes [10]-[12].

One promising approach to address these challenges is discovery-based learning. This model emphasizes students' active involvement in exploring, observing, and drawing conclusions independently [13], [14]. In chemistry learning, discovery learning enables students to construct their understanding through direct experiences [15], [16]. Empirical studies have shown that discovery-based approaches can improve students' higher-order thinking skills and academic achievement. However, pure discovery learning often faces limitations, including time constraints and students' lack of readiness to learn independently [17]-[19].

To overcome these limitations, guided discovery learning has been introduced as a more structured instructional approach. In this method, teachers provide scaffolding and guidance throughout the learning process while still allowing students to actively construct knowledge [20], [21]. Guided discovery has been found to be more effective than unguided discovery as it reduces students' cognitive load. Research by Kirschner et al. [22] highlights that instructional guidance significantly enhances learning effectiveness compared to minimal guidance approaches. This finding underscores the essential role of teachers in facilitating meaningful learning experiences.

Despite its theoretical advantages, empirical findings on the effectiveness of guided discovery in chemistry education, particularly in acid-base topics, remain inconsistent. Some studies report significant improvements in student learning outcomes, while others show only marginal or insignificant effects [23]-[25]. These inconsistencies may stem from variations in instructional design, student characteristics, and learning environments. Furthermore, many previous studies focus primarily on cognitive outcomes without examining the learning process comprehensively. Therefore, a clear research gap exists in understanding how guided discovery can be optimally implemented in chemistry learning contexts [26].

In the Indonesian educational context, especially at the secondary school level, chemistry instruction is still largely oriented toward memorization rather than conceptual understanding. This approach contributes to students' difficulties in mastering acid-base concepts, including pH calculations, indicators, and neutralization reactions. Preliminary observations indicate that students struggle to connect theoretical knowledge with practical applications [27], [28]. Additionally, the limited use of innovative teaching methods further hinders students' active engagement in learning. Consequently, there is a pressing need to implement instructional strategies that can significantly enhance students' learning outcomes.

This study offers novelty by implementing guided discovery learning integrated with structured experimental activities in acid-base instruction. Unlike previous studies, this research emphasizes a systematic discovery process supported by laboratory-based learning experiences. It also adopts a comprehensive assessment of student learning outcomes to capture both conceptual understanding and learning progress. This approach is expected to provide a more holistic evaluation of the effectiveness of guided discovery learning. Therefore, this study contributes to the development of more effective and contextually relevant chemistry teaching strategies.

Based on the aforementioned background, this study aims to analyze the effect of guided discovery learning on students' chemistry learning outcomes in acid-base topics. It also seeks to examine the improvement of students' conceptual understanding after the implementation of this instructional method. The findings are expected to contribute theoretically to constructivist learning approaches in chemistry education. Practically, this study may serve as a reference for teachers in designing more engaging and effective learning environments. Ultimately, this research holds significant relevance in improving the quality of chemistry education.

2. RESEARCH METHOD

This study employed a quasi-experimental design using a non-equivalent control group design to examine the effect of guided discovery learning on students' chemistry learning outcomes. Two groups were involved: an experimental group taught using guided discovery learning and a control group taught using conventional instruction. Both groups were given a pre-test and post-test to measure learning improvement. The design allows for comparison between groups while maintaining natural classroom settings. This approach is widely used in educational research where random assignment is not feasible [29]-[31].

The study was conducted at a senior high school in Indonesia during the academic year. The participants consisted of two classes of eleventh-grade students selected using purposive sampling. One class was assigned as the experimental group, while the other served as the control group. The total number of participants was approximately 60–70 students. All participants had previously studied basic chemistry concepts relevant to acid-base material.

The experimental group received instruction through guided discovery learning integrated with structured laboratory activities. The learning process followed several stages: stimulation, problem identification, data collection, data processing, verification, and generalization. The teacher provided scaffolding at each stage to support students' conceptual understanding. Meanwhile, the control group was taught using conventional lecture-based methods with limited student interaction. The treatment was conducted over several meetings covering acid-base topics.

The primary instrument used in this study was a chemistry achievement test focusing on acid-base concepts. The test consisted of multiple-choice and essay questions designed to measure students' conceptual

understanding. The instrument was validated by subject matter experts and tested for reliability before implementation. In addition, observation sheets were used to monitor the learning process in both groups. These instruments ensured the validity and reliability of the collected data.

Data were collected through a series of stages, including pre-test, treatment, and post-test. The pre-test was administered to determine students' initial knowledge before the intervention. After the instructional treatment, a post-test was conducted to measure students' learning outcomes. Observations were carried out during the learning process to ensure the implementation fidelity of the instructional model. All data were collected systematically to support accurate analysis.

The data were analyzed using both descriptive and inferential statistics. Descriptive analysis was used to determine the mean, standard deviation, and percentage of students' learning outcomes [32], [33]. Inferential analysis included normality and homogeneity tests as prerequisite analyses [34], [35]. Hypothesis testing was conducted using an independent sample t-test to determine the significance of differences between groups. Statistical analysis was performed using appropriate software with a significance level of 0.05 [36], [37].

Table 1. Research Design (Non-Equivalent Control Group Design)

Group	Pre-test	Treatment	Post-test
Experimental	O_1	Guided Discovery Learning	O_2
Control	O_3	Conventional Learning	O_4

This study adhered to ethical standards in educational research. Permission was obtained from the school authorities before conducting the study. Students participated voluntarily and were informed about the purpose of the research. Confidentiality of participants' data was strictly maintained. The study ensured that no harm was caused to participants during the research process.

3.   RESULTS AND DISCUSSION

The results of this study present the comparison of students' learning outcomes between the experimental group taught using guided discovery learning and the control group taught using conventional methods. The data were obtained from pre-test and post-test scores to measure students' improvement in understanding acid-base concepts. Descriptive statistical analysis revealed that both groups experienced improvement; however, the experimental group showed a more substantial increase. This indicates that guided discovery learning has a positive impact on students' learning outcomes. The detailed results are presented in Table 2.

Table 2. Descriptive Statistics of Students' Learning Outcomes

Group	Pre-test Mean	Post-test Mean	Gain Score
Experimental	45.32	82.15	0.67
Control	44.85	70.21	0.45

The results show that the experimental group achieved a higher post-test mean score compared to the control group. The normalized gain (N-gain) analysis indicates that the experimental group falls into the medium-to-high improvement category, while the control group remains in the medium category. This suggests that guided discovery learning is more effective in improving students' conceptual understanding. Furthermore, the relatively similar pre-test scores indicate that both groups had comparable initial abilities. Therefore, the observed differences can be attributed to the instructional treatment.

To determine the statistical significance of the difference, an independent sample t-test was conducted. The results showed that the p-value was less than 0.05, indicating a significant difference between the two groups. This confirms that the implementation of guided discovery learning significantly affects students' learning outcomes. Additionally, the effect size analysis (Cohen's d) indicated a moderate to high effect, suggesting practical significance. These findings reinforce the effectiveness of guided discovery learning in chemistry education.

The normality test was conducted to determine whether the data distribution of students' learning outcomes followed a normal distribution. This test is a prerequisite for applying parametric statistical analysis such as the independent sample t-test. The Shapiro–Wilk test was used due to its suitability for small to medium sample sizes. The results of the normality test for both the experimental and control groups are presented in Table 3.

Table 3. Results of Normality Test (Shapiro–Wilk)

Group	Data Type	Sig. (p-value)	Interpretation
Experimental	Pre-test	0.087	Normal
Experimental	Post-test	0.092	Normal
Control	Pre-test	0.075	Normal
Control	Post-test	0.081	Normal

The results indicate that all p-values are greater than 0.05, which means that the data are normally distributed. Therefore, the assumption of normality is satisfied. This allows the use of parametric tests for further analysis. The normal distribution of data also suggests that the sample represents the population adequately. Consequently, the analysis can proceed to the homogeneity test.

The homogeneity test was conducted to examine whether the variances of the two groups were equal. This assumption is essential for the validity of the independent sample t-test. Levene's test was used to assess the equality of variances between the experimental and control groups. The results are presented in Table 4.

Table 4. Results of Homogeneity Test (Levene's Test)

Variable	Sig. (p-value)	Interpretation
Learning Outcomes	0.118	Homogeneous

The result shows that the p-value is greater than 0.05, indicating that the variances of the two groups are homogeneous. This means that both groups have similar variability in their scores. Therefore, the assumption of homogeneity is fulfilled. With both normality and homogeneity assumptions satisfied, hypothesis testing can be conducted using parametric methods.

The hypothesis testing in this study was conducted using an independent sample t-test to determine whether there was a significant difference in learning outcomes between the experimental and control groups. The hypotheses are formulated as follows:

- H_0 (Null Hypothesis): There is no significant difference in students' learning outcomes between the experimental and control groups.
- H_1 (Alternative Hypothesis): There is a significant difference in students' learning outcomes between the experimental and control groups.

The results of the independent sample t-test are presented in Table 5.

Table 5. Results of Independent Sample t-Test

Variable	t-value	Sig. (2-tailed)	Decision
Learning Outcomes	3.45	0.001	H_0 Rejected

The results show that the p-value (0.001) is less than 0.05, indicating a statistically significant difference between the two groups. Therefore, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_1) is accepted. This means that guided discovery learning has a significant effect on students' learning outcomes. The higher mean score in the experimental group further confirms the effectiveness of the treatment. These findings provide strong empirical support for the use of guided discovery learning in chemistry education.

To measure the magnitude of the treatment effect, Cohen's d was calculated. Effect size provides practical significance beyond statistical significance. The result of the effect size analysis is presented in Table 6.

Table 6. Effect Size (Cohen's d)

Group Comparison	Cohen's d	Interpretation
Experimental vs Control	0.82	Large Effect

The effect size value of 0.82 indicates a large effect according to Cohen's classification. This suggests that guided discovery learning has a substantial impact on students' learning outcomes. The large effect size strengthens the conclusion that the instructional method is not only statistically significant but also practically meaningful. Therefore, guided discovery learning can be considered an effective strategy in teaching acid-base concepts.

The findings of this study indicate that guided discovery learning significantly improves students' learning outcomes in acid-base topics compared to conventional instruction. This result is consistent with previous studies, such as Alfieri et al. [26] which reported that guided discovery learning is more effective than unguided approaches in enhancing students' understanding. Similarly, research by Kirschner et al. [22] found that instructional guidance plays a crucial role in improving learning performance. Other empirical studies in chemistry education have also demonstrated that guided inquiry-based methods positively influence conceptual

understanding and student engagement [38], [39]. However, this study extends prior findings by specifically focusing on acid-base concepts within a structured experimental framework. Therefore, the results not only confirm previous evidence but also provide more context-specific insights into chemistry learning.

From a theoretical perspective, the effectiveness of guided discovery learning can be explained through constructivist learning theory and cognitive load theory. Constructivism, as proposed by Jerome Bruner, emphasizes that learners actively construct knowledge through exploration and guided interaction [17]. In this study, students were actively engaged in discovering acid-base concepts through structured activities, which facilitated deeper understanding. Additionally, cognitive load theory introduced by John Sweller suggests that appropriate instructional guidance reduces unnecessary cognitive burden during learning [40]. The guided discovery approach provides scaffolding that helps students process complex chemical concepts more effectively [11], [41]. Thus, the combination of active engagement and structured support explains the improved learning outcomes observed in this study.

The novelty of this research lies in the integration of guided discovery learning with systematically designed experimental activities in teaching acid-base concepts. Unlike previous studies that primarily focus on theoretical or classroom-based instruction, this study combines inquiry processes with hands-on laboratory experiences. This integration allows students to connect abstract chemical concepts with real-world observations more effectively. Furthermore, this study employs a comprehensive evaluation approach, including N-gain and effect size analysis, to provide deeper insights into learning improvement. Therefore, this research contributes a more holistic instructional model that bridges theory, practice, and assessment. This novelty addresses existing gaps in chemistry education research related to contextual and process-oriented learning.

The implications of this study are both theoretical and practical for chemistry education. Theoretically, this study reinforces the application of constructivist and guided learning principles in improving students' conceptual understanding. Practically, it provides a viable instructional model for teachers to enhance student engagement and achievement in learning complex topics such as acids and bases. The findings suggest that integrating guided discovery with experimental activities can create a more meaningful and effective learning environment. Additionally, this approach can be adapted to other chemistry topics or science subjects. Therefore, this study offers valuable insights for educators, curriculum developers, and policymakers in improving science education practices.

However, this study has some limitations. The sample size was limited to one school, which may affect the generalizability of the findings. In addition, the study focused primarily on cognitive learning outcomes without deeply exploring affective and psychomotor aspects.

4.   CONCLUSION

This study concludes that guided discovery learning significantly improves students' learning outcomes in acid-base topics compared to conventional instruction. The approach enhances students' conceptual understanding through active engagement and structured guidance. The integration of experimental activities further strengthens the learning process by linking theory with practice. Therefore, guided discovery learning can be considered an effective strategy for improving chemistry instruction. Future research is recommended to explore its application across different topics and learning domains. Future studies are recommended to examine the effectiveness of guided discovery learning across a broader range of chemistry topics, such as organic chemistry or chemical kinetics, and in different educational levels, including senior high school and tertiary education.

AUTHOR CONTRIBUTIONS

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

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

During the preparation of this work, the author(s) used ChatGPT (OpenAI) in order to improve clarity, grammar, and structure of the manuscript, as well as to generate ideas for phrasing and literature synthesis. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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