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Evaluation of Laboratory Activities and Students' Self-Regulated Learning Using an Inquiry-Based Approach

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Abstract: This study aims to examine the effects of guided inquiry and open inquiry approaches on students' laboratory activity scores and self-regulated learning in chemistry instruction. A quasi-experimental research design was employed, involving two groups: a guided inquiry group consisting of 25 students and an open inquiry group consisting of 23 students. Laboratory activity was assessed using a rubric covering pre-lab, lab work, and post-lab activities. A questionnaire was used to measure students' SRL across five dimensions: metacognitive skills, time management, environmental structuring, persistence, and help-seeking. The results showed that the guided inquiry group achieved the highest laboratory activity and SRL scores. The pre-lab, lab-work, and post-lab scores were consistent with the group's overall laboratory activity score. Among SRL dimensions, the highest scores in the guided inquiry group were observed for metacognitive skills and environmental structuring. In contrast, the open inquiry group showed the highest SRL score in the help-seeking dimension. ANCOVA analysis revealed a significant relationship between the inquiry approach and both laboratory activity scores and students' SRL. Students' tendency to experience difficulty initiating the investigative stages contributed to the lower effectiveness of open inquiry. These findings indicate that the effectiveness of guided inquiry is attributed to its structured support, which facilitates students in initiating the investigative phase. In contrast, although open inquiry provides greater opportunities for exploration, its limited implementation in instructional practice may impede students' ability to effectively initiate the investigative process.

Keywords: inquiry approach, chemistry instruction, metacognition, motivation, pre-laboratory.

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INTRODUCTION

As a core component of science education, laboratory-based learning has long been integral to the chemistry curriculum. Currently, university-level chemistry curricula emphasize the development of students' thinking skills, technical skills, and social skills. All of these competencies can be fostered through laboratory-based learning (Altowaiji et al., 2021). The development of both dry and wet laboratory activities continues to evolve, and the integration of these laboratories with multimedia has been widely implemented to ensure flexibility across various learning conditions (Sommers et al., 2021; Mosiagin et al., 2021).

Since the onset of the COVID-19 pandemic, laboratory experiments have not been conducted under normal conditions (Andrews et al., 2020). This is particularly concerning because chemistry is a discipline that heavily relies on experimental work. As a result, home-based experiments and multimedia-supported instruction were developed as alternative approaches during the pandemic. However, these simplified methods could only be implemented to a limited extent and often failed to achieve the intended experimental learning objectives (Miles & Wells, 2020; Schultz et al., 2020; Selco, 2020; Villanueva & Zimmermann, 2020).

The implementation of laboratory activities during the pandemic led to suboptimal learning outcomes. Several factors may explain this issue, including changes in instructional techniques and delivery. Ineffective instruction may have resulted from varying student learning conditions in online environments, insufficient prior knowledge, unclear experimental instructions, and limited feedback from lecturers, all of which contributed to the reduced effectiveness of laboratory-based learning during the pandemic (Azubuike et al., 2021; Bacher-Hicks et al., 2021; Maglio et al., 2025).

At the university level, laboratory-based learning generally consists of three main components: pre-lab work, lab work, and post-lab work. These activities are integrated with classroom instruction. The pre-lab stage focuses on preparation for the investigation, particularly strengthening prior knowledge and planning experimental procedures. The lab-work stage involves conducting investigations in accordance with the plans established during the pre-lab phase. The post-lab stage includes reporting findings and receiving feedback on the completed investigation (Jolley et al., 2021; Reid & Shah, 2007).

Previous research indicates that students' responses to laboratory-based learning are influenced by the quality and type of instructional design, as well as the interactions and learning experiences provided (Rozo-García et al., 2024). The use of expository or "cookbook" laboratory approaches has been shown to limit meaningful learning experiences and constrain students' creativity in conducting independent exploration (Agustian, 2025). The investigative method remained largely expository, as students were adjusting to post-pandemic learning conditions. However, expository methods cannot be implemented continuously because they are less effective in developing students' higher-order thinking skills (Seery, 2020).

Inquiry-based learning offers a promising alternative in the post-pandemic context, particularly in higher education (Willey et al., 2020). This approach aims to reintegrate three essential elements of learning within a unified framework of higher education outcomes: cognitive presence, social presence, and learning process presence. The relationships among these elements can be effectively explored through inquiry-based approaches (Lau et al., 2021).

Inquiry-based learning is grounded in constructivist theory, which provides learners with opportunities to actively construct knowledge from collected data. Constructivism is highly relevant to science learning, as it views students as unique individuals with diverse cognitive processes (Johnstone, 2006). Learning begins with students articulating their existing understanding, restructuring their knowledge, applying new concepts, and comparing new understandings with prior conceptions (Le & Nguyen, 2024). In laboratory-based instruction, inquiry is characterized by students developing their own observational procedures to general conclusions from specific findings (Domin, 1999).

In chemistry laboratory instruction, inquiry is categorized into four levels: Level 0 (verification), Level 1 (structured inquiry), Level 2 (guided inquiry), and Level 3 (open inquiry) (Fay et al., 2007). These levels differ in terms of the problem, the degree of procedural design, and the problem-solving strategies employed. The higher the inquiry level, the greater the opportunity for students to work independently. In higher education settings, guided inquiry and open inquiry are recommended because they enhance students' conceptual understanding in chemistry (Mulia, 2025; Poya, 2026; Zemene et al., 2025).

Inquiry-based learning is student-centered and therefore influenced by internal student factors (Reid & Shah, 2007). Internal factors have been reported to significantly contribute to learning success, especially in the post-pandemic context

(Anthony et al., 2022). One critical internal factor is self-regulated learning (SRL). SRL refers to students' ability to plan, monitor, and evaluate their learning strategies, as well as to regulate their actions and adjust strategies to achieve academic success (Zimmerman, 2002). Guided and open inquiry approaches place strong emphasis on students' ability to regulate their own learning strategies effectively.

Inquiry-based activities constitute a fundamental component of chemistry education and, therefore, require well-designed instructional approaches for effective implementation. In the post-COVID-19 context, students are expected to undergo a learning recovery process, particularly in re-engaging with scientific practices and developing familiarity with the scientific process (Maglio et al., 2025). Laboratory-based learning environments demand that students not only engage in scientific inquiry but also regulate their own learning processes. In this regard, inquiry-based models offer considerable potential to support students in actively controlling and reflecting on their learning experiences (Agustian, 2025; Rozo-Garcia et al., 2024).

Several studies have compared open inquiry and guided inquiry in laboratory-based learning, particularly at the elementary level, to examine their effects on students' science process skills and conceptual understanding (Karlina et al., 2024). In addition, Areepattamannil (2025) investigated the differences between these inquiry approaches in terms of academic achievement and learning engagement. Previous studies have predominantly focused on comparing guided inquiry and open inquiry within general classroom contexts, with relatively limited attention given to their application in laboratory settings. Comprehensive investigations specifically addressing laboratory activities remain scarce. Moreover, the extent to which guided inquiry and open inquiry approaches influence students' self-regulated learning (SRL) in laboratory environments has not been sufficiently explored. This gap is notable, as laboratory activities inherently require students to actively regulate their learning processes, including the management of strategies, time, and reflective practices, core components of SRL.

This study aims to examine the effects of guided inquiry and open inquiry approaches on students' laboratory activities and self-regulated learning (SRL). The study addressed the following research questions: (1) To what extent does the implementation of guided inquiry and open inquiry affect students' laboratory activity scores? (2) To what extent does the implementation of guided inquiry and open inquiry affect students' self-regulated learning (SRL) scores?

METHOD

Participants

Participants were selected using a convenience sampling technique. This study involved two classes of chemistry education students ($N = 48$) at Universitas Mataram. The first class employed a guided inquiry approach, whereas the second employed an open inquiry approach. The demographic characteristics of both groups are presented in Table 1.

Table 1. Demographic characteristics of the research sample

	Group I	Group II
Gender		
Male	4 (16%)	3 (13%)
Female	21 (84%)	20 (87%)
Age		
18year	15 (60%)	12 (52%)
19year	10 (40%)	11 (48%)

Research Design and Procedure

Prior to the intervention, a pre-implementation phase was conducted using the existing laboratory-based learning procedures. This phase aimed to ensure equivalence in baseline conditions before the intervention (Shadish et al., 2002). Laboratory activity scores and self-regulated learning (SRL) scores were collected as baseline measures. Both the pre-implementation and intervention phases comprised an equal number of laboratory sessions, each spanning seven weeks with a duration of 150 minutes per session. Each phase included two investigative sessions. During the pre-implementation phase, the topic focused on carbohydrates, with investigative activities involving qualitative and quantitative analyses. In the intervention phase, the topic shifted to fats, with corresponding investigative activities consisting of qualitative and quantitative analyses of fats. Timeline of learning scenario implementation is presented in Table 2.

Table 2. Timeline of scenario implementation

Phase	Week	Activity
Pre-Implementation	1-2	Build students' prior knowledge
	3	Pre-lab/Develop investigation plan
	4	Lab work: qualitative analysis of carbohydrates
	5	Lab work: quantitative analysis of carbohydrates
	6	Report investigation result
	7	Feedback and evaluation
Implementation	1-2	Build students' prior knowledge
	3	Pre-lab/Develop investigation plan
	4	Lab work: qualitative analysis of fatty acids
	5	Lab work: quantitative analysis of fatty acids
	6	Report investigation result
	7	Feedback and evaluation

Subsequently, guided inquiry and open inquiry were implemented over an equal number of sessions in each group. The learning scenarios for both groups are presented in Tables 3 and 4.

Pre-lab and lab-work activities were assessed by observers who had received prior training on the use of the assessment rubric. The lecturer evaluated post-lab activities after the

Table 3. Guided inquiry learning scenario

Lecturer	Students
1. The lecturer explains key concepts to build students' prior knowledge.	1. Students pay attention to and take notes on key points from the lecturer's explanation.
2 The lecturer provides questions or themes for students to discuss.	2. Students record the questions or themes provided by the lecturer.
3. The lecturer instructs students to formulate hypotheses based on the given questions.	3. Students formulate hypotheses according to the lecturer's instructions.
4. The lecturer directs students to design an investigation plan.	4. Students design an investigation plan in groups based on the lecturer's guidance.
5. The lecturer guides students in investigating according to their proposed plan	5. Students conduct the investigation in groups according to the agreed plan.
6. The lecturer provides feedback on students' reports	6. Students collect and analyze data.
	7. Students report the results of their investigation

Table 4. Open inquiry learning scenario

Lecturer	Students
The lecturer explains key concepts to build students' prior knowledge.	Students pay attention to and take notes on key points from the lecturer's explanation.
The lecturer instructs students to develop an investigation plan based on the agreed-upon topic.	Students formulate research questions and hypotheses in groups.
The lecturer provides feedback on students' reports	Students develop an investigation plan based on the questions and hypotheses they have generated.
	Students conduct the investigation in groups according to the proposed plan.
	Students collect and analyze the data.
	Students report the results of their investigation

investigation had been completed. One observer accompanied each group during the laboratory sessions. SRL data were collected using the questionnaire developed by the researchers.

Instruments

Two instruments were used in this study: one to measure students' laboratory activities and another to assess their self-regulated learning (SRL). Laboratory activities were evaluated using a rubric covering three stages: pre-lab, lab work, and post-lab. The assessment components for these three laboratory activities are presented in Table 5.

The assessment rubric was developed by the researchers based on Kumar (2010) and validated by five experts in Chemistry Education and Science Education. The validation results showed a validity score of 0.722 and an Intra-class Correlation Coefficient (ICC) of 0.667 (Moderate), indicating that the instrument is both valid and reliable (Ko & Li, 2016). The laboratory activity rubric is provided in the supplementary materials.

The questionnaire used to measure students' self-regulated learning (SRL) was adapted from Jansen et al. (2017). SRL was assessed across five dimensions: metacognitive skills, time management, environmental structuring, persistence, and help-seeking. A total of 25 items were developed, with each dimension including both positively and negatively worded statements. Students responded using a five-point scale, with the scoring scheme shown in Table 6. The research questionnaire was first validated by five experts based on its relevance to the measured dimensions. Revisions were made in accordance with the experts' suggestions. A total of 15 positively worded items and 10 negatively worded items were deemed appropriate for inclusion in the SRL questionnaire. The reliability analysis of the SRL questionnaire yielded a Cronbach's alpha coefficient of 0.838, indicating good internal consistency.

Table 5. Assessment components of laboratory activities

Laboratory Activities	Research components
Pre-Lab	Investigation Design
Lab-Work	1. Procedural skills
	2. Observation skills
	3. Interpretation skills
	4. Communication skills
	5. Time management skills
Post-Lab	1. Presentation skills
	2. Investigation report

Table 6. Questionnaire response options and scoring

Response Options	Score	
	Positive Statement	Negative Statement
Strongly agree	5	1
Agree	4	2
Neutral	3	3
Disagree	2	4
Strongly disagree	1	5

Data Analysis Techniques

Scores for each laboratory activity component and SRL dimension were tabulated, and the mean and standard deviation were calculated. The effects of guided inquiry and open inquiry on students' laboratory activity scores and self-regulated learning (SRL) were examined using analysis of covariance (ANCOVA) conducted in SPSS version 21. The pretest scores of both variables were included as covariates to control for initial differences.

RESULT AND DISCUSSION

Research Question 1

The descriptive statistical analysis (Table 7) indicates that the pretest scores for laboratory activities in the guided inquiry and open inquiry groups were 64.582 (SD = 3.944) and 68.311 (SD = 10.716), respectively. Post-test scores increased in both groups relative to their pretest performance. Specifically, the guided inquiry group achieved a higher post-test mean score of 80.609 (SD = 7.908), whereas the open inquiry group obtained a post-test mean of 73.822 (SD = 7.991).

The ANCOVA results (Table 8) indicate that the type of inquiry (guided inquiry versus open inquiry) had a significant effect on students' final laboratory activity scores after controlling for initial scores as covariates. A statistically significant difference was observed between the two groups, F (1, 45) = 15.295, p < .001, η^2 = 0.254, suggesting a substantial effect of the treatment. In addition, the covariate (initial score) was a significant predictor of the final score, F (1, 45) = 43.117, p < .001, η^2 = 0.489. These findings indicate that both inquiry approaches contributed to improvements in laboratory activity scores, beyond the effect of students' initial performance.

Table 7. Descriptive statistics of students' laboratory activity scores

	Pretest		Posttest	
	Guided Inquiry	Open Inquiry	Guided Inquiry	Open Inquiry
N	25	23	25	23
Mean	64.582	68.311	80.609	73.822
Std. Deviation	3.944	10.716	7.908	7.991
Minimum	56.736	44.917	64.167	53.125
Maximum	72.292	71.412	93.055	80.208

Table 8. ANCOVA results for laboratory activity scores

Source	SS	df	MS	F	p	η^2	Adj. R^2
Pre-test	1421.763	1	1421.763	43.117	0.000	0.489	0.552
Group	504.366	1	504.366	15.295	0.000	0.254	
Error	1483.867	45	32.975				

$p < 0.05$

The scores for each component of laboratory activity were generally higher in the guided inquiry group than in the open inquiry group (see Figure 1). For pre-laboratory activities, the mean scores were 82.233 (SD = 14.053) for the guided inquiry group and 78.069 (SD = 12.602) for the open inquiry group. Similarly, for laboratory work activities, the guided inquiry group achieved a higher mean score of 81.315 (SD = 7.038), compared to 75.504 (SD = 10.771) in the open inquiry group. In contrast, post-laboratory activity scores were comparable between the two groups, with mean scores of 78.275 (SD = 6.419) for the guided inquiry group and 78.822 (SD = 6.112) for the open inquiry group.

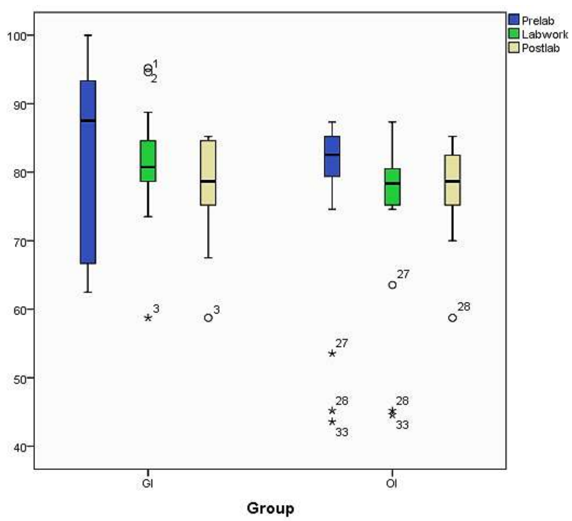

Figure 1. Laboratory activity scores of the guided inquiry and open inquiry

The effects of the intervention on each laboratory sub-activity were also examined using ANCOVA, with initial scores included as covariates. The results revealed significant effects for both pre-laboratory and laboratory work activities. Specifically, a significant effect was found for pre-laboratory scores, F (1, 45) = 34.457, $p < .001$, ç² = 0.434, and for laboratory work scores, F (1, 45) = 4.521, $p = .039$, ç² = 0.091, indicating that the treatment significantly influenced performance in these sub-activities. In contrast, no significant effect was observed for post-laboratory activities, F (1, 45) = 1.699, p = .203, ç² = 0.036, suggesting that the intervention did not significantly affect post-laboratory scores.

Research Question 2

Consistent with the laboratory activity results, the SRL scores of the guided inquiry group were higher than those of the open inquiry group. The mean SRL score for the guided inquiry group was 3.451, while the open inquiry group obtained a mean score of 2.825. The highest-scoring SRL dimensions differed between the two groups. In the guided inquiry group, metacognitive skills and environmental structuring showed the highest scores, while time management had the lowest score. In contrast, the open inquiry group achieved the highest score in the help-seeking dimension, whereas the lowest score was found in the same dimension as in the guided inquiry group (Table 9).

The ANCOVA results (Table 10) indicate that the type of inquiry (guided inquiry versus open inquiry) had a significant effect on students' final self-regulated learning (SRL) scores after

Table 9. Score dimension of SRL in guided and open inquiry

Dimension of SRL	Guided Inquiry		Open Inquiry	
	M	SD	M	SD
Metacognitive	3.606	0.190	2.832	0.686
Time Management	3.280	0.267	2.826	0.667
Environmental structuring	3.712	0.327	2.956	0.669
Persistence	3.336	0.236	2.409	0.388
Help-seeking	3.320	0.326	3.101	0.536

controlling for initial scores as a covariate. A statistically significant difference was observed between the two groups, $F(1, 45) = 65.068$, $p < .001$, $\eta^2 = 0.591$, indicating a large effect of the treatment on SRL outcomes. In addition, the covariate (initial score) was a significant predictor of the final SRL score, $F(1, 45) = 29.045$, $p < .001$, $\eta^2 = 0.392$. These findings suggest that both inquiry approaches contributed significantly to improvements in SRL, beyond the influence of students' initial levels.

The results further indicate that both guided inquiry and open inquiry significantly influenced several dimensions of self-regulated learning (SRL). Specifically, significant effects were observed in the metacognitive, time management, persistence, and help-seeking dimensions. In contrast, no significant differences were found in the environmental structuring dimension, suggesting that the intervention did not have a measurable impact on this aspect of SRL (Table 11).

Table 10. ANCOVA results for SRL scores

Source	SS	df	MS	F	p	η^2	Adj. R^2
Pre-test	2.074	1	2.074	29.045	0.000	0.392	0.664
Group	4.646	1	4.646	65.068	0.000	0.591	
Error	3.213	45	0.071				

$p < 0.05$

Table 11. ANCOVA results for SRL dimension scores

Dimension of SRL	F (1, 45)	p	η^2	Adj. R^2
Metacognitive	40.356	0.000	0.473	0.550
Time Management	4.674	0.036	0.094	0.693
Environmental structuring	2.595	0.114	0.055	0.026
Persistence	21.691	0.000	0.325	0.952
Help-seeking	20.196	0.000	0.310	0.327

$p < 0.05$

This study found that guided inquiry led to higher laboratory activity scores than open inquiry. This finding contrasts with that of Owolade et al. (2022), who reported that open inquiry had a stronger impact than guided inquiry. However, the present results are consistent with studies by Hamed & Rebello (2026), which showed that guided inquiry can produce better learning outcomes than open inquiry.

Difficulties in implementing open inquiry may stem from several factors. First, students may have limited science process skills, such as formulating hypotheses, generating research questions, and identifying variables. Second, students may be unfamiliar with inquiry-based learning if it has not been previously implemented. Third, students often struggle to determine how to initiate the investigation process (Hamed & Rebello, 2026). According to Deffner & Hermanns (2025), open inquiry allows students to design and conduct investigations based on their own plans. Therefore, the success of the investigation largely depends on the quality of the investigation design. The findings showed that pre-lab scores in the guided inquiry group were higher than those in the open inquiry group, indicating that students in the guided inquiry group developed stronger investigation plans. This difference subsequently influenced their lab work and post-lab performance.

The average scores for each component of the laboratory activities were higher in the guided inquiry group than in the open inquiry group. In the open inquiry group, relatively low scores were observed in both laboratory assignments and post-laboratory assessments across the two learning topics. Classroom observations revealed that students experienced difficulties in formulating research questions and designing inquiry procedures. These skills (question formulation and investigation design) are widely recognized as among the most challenging aspects of open-ended inquiry. In contrast, structured and guided inquiry approaches tend to be more accessible to students, as they provide greater instructional support in these areas. Nevertheless, open-ended inquiry remains a valuable long-term goal in science education and may be more effectively implemented gradually and on a limited scale.

A key factor contributing to the success of guided inquiry in this study was students' emotional experience during the investigation process. Feelings of success can foster enjoyment, motivation, and self-confidence at each stage of learning (Hamed & Rebello, 2026). In this study, students who completed investigations demonstrated higher motivation to engage in subsequent topics. In contrast, students in the open inquiry group showed different patterns, suggesting that further research is needed to better understand the implementation of open inquiry.

In post-lab activities, particularly presentations and report writing, differences were also observed between the two groups. Students in the guided inquiry group presented stronger arguments, both orally and in writing, when explaining their findings than those in the open inquiry group. During instruction, students in the open inquiry group tended to be slower to understand instructions and locate relevant literature, which may explain their lower post-lab scores. Previous research has indicated that open inquiry may be negatively associated with students' literacy and numeracy skills when prior knowledge is insufficient to support independent information seeking (Björnhammer et al., 2025; Schneider & Simonsmeier, 2025; Hörnlein & Kulgemeyer, 2025).

The highest SRL scores in the guided inquiry group were found in the metacognitive skills dimension, which aligned with improvements in laboratory activity performance. Kayacan and Ektem (2019) similarly found that strong SRL supports self-directed learning in laboratory activities. Beyond laboratory contexts, SRL has been shown to influence learning processes, attitudes, and outcomes, including in online learning environments (Faza & Lestari, 2025; Stalmach et al., 2023; Schuster et al., 2020).

This study found that metacognitive skills and environmental structuring had the highest scores. Metacognitive skills involve the ability to plan, regulate, and evaluate learning to achieve goals (Fahrni et al., 2025). These skills supported students' performance in pre-lab, lab work, and post-lab activities within the guided inquiry group. Strong metacognitive skills also enhance environmental structuring and other SRL components. Zheng & Zhang (2020) argued that metacognitive competence supports self-motivation and the development of positive attitudes toward learning success. This aligns with Marquez-Fernandez et al. (2025)'s view that students' positive feelings during inquiry contribute to successful learning.

In contrast, the open inquiry group showed the highest SRL scores in the help-seeking dimension. This may reflect students' limited prior knowledge, which led them to seek additional assistance to achieve their learning goals. Students adopt strategies that improve performance when they perceive a gap between effort and outcomes. One such strategy is seeking help from peers (Marquez-Fernandez et al., 2025). The elevated help-seeking scores in the open inquiry group may indicate the development of students' self-regulatory capacities. Previous research has shown that help-seeking reflects learners' ability to manage their learning processes, identify knowledge gaps, and proactively seek feedback to enhance understanding (Khuder, 2025). In addition, help-seeking is considered a constructive learning strategy that facilitates collaborative knowledge construction while fostering independent learning behaviors (Cheng, 2025).

Although open inquiry was not highly successful in this study, efforts to implement it in higher education remain important for developing students' thinking skills. To improve effectiveness, instructors should strengthen students' prior knowledge each semester to support question formulation, hypothesis development, and the design of investigations (Schneider & Simonsmeier, 2025; Baur & Emden, 2020). Lecturers can adopt a gradual, scaffolded inquiry approach to support post-pandemic learning recovery. Continuous and progressive implementation of inquiry is expected to train students to think systematically and become more accustomed to inquiry processes. Although several studies recommend Level 2 (guided inquiry) and Level 3 (open inquiry) for higher education, instruction may begin with structured inquiry to better prepare students for more independent inquiry levels

CONCLUSION

The study's results indicate a significant relationship between the inquiry approach and both students' laboratory activity scores and their self-regulated learning (SRL). The implementation of guided inquiry resulted in higher laboratory activity and SRL scores compared to the open inquiry group. These findings are consistent with improvements observed across pre-lab, lab-work, and post-lab activities. The highest SRL dimensions in the guided inquiry group were metacognitive skills and environmental structuring, whereas help-seeking was the highest-scoring SRL dimension in the open inquiry group.

These findings indicate that laboratory-based learning with structured guidance is essential, particularly for the development of students' laboratory skills. However, this study has several limitations. The relatively small sample size, combined with the use of convenience sampling, limits the representativeness of the participants, as certain characteristics may not adequately reflect the broader population. In addition, the use of a quasi-experimental design alongside convenience sampling suggests that some extraneous variables may not have been fully controlled. Consequently, the findings should be interpreted within their specific context and cannot be readily generalized to a wider or more homogeneous population. Future studies are recommended to include larger and more diverse samples. Additionally, more in-depth investigation is needed to examine the relationships among prior knowledge, independence, and students' readiness for open inquiry.

DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

In the writing of this manuscript, the author(s) employed ChatGPT (OpenAI, 2026) to assist with language refinement/proofreading. The author(s) have reviewed and edited the content generated by this tool and assume full responsibility for the content of the published article.

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