

Scientific inquiry in biology: exploring university students' understanding of experiment planning, implementation, and interpretation

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Abstract

Scientific inquiry in biology: exploring university students' understanding of experiment planning, implementation, and interpretation. Biology learning based on scientific inquiry requires university students to understand experimentation as a process involving planning, conducting, and interpreting results. This study aimed to analyze university students' understanding of scientific inquiry through biological experiments and the relationships among these aspects. A descriptive correlational study used a survey of 41 first-semester Basic Biology students and assessment of 10 group experimental reports. Survey responses were analyzed descriptively and using Spearman's correlation; report assessment provided a complementary descriptive perspective. Category means were 4.08 for planning, 3.96 for implementation, and 4.06 for interpretation, with positive correlations ranging from 0.748 to 0.861. Descriptive report observations indicated difficulties in linking data with biological concepts and supporting explanations with evidence. The study extends the cited outcome-oriented inquiry research by mapping associations among three experimental domains within introductory university biology and considering those perceptions alongside group written work. The findings suggest connecting experimental decisions and observations with explicit guidance for evidence-based explanations. Because survey responses and group reports represent different units of analysis, the findings do not establish an individual perception–performance discrepancy.

Keywords: Scientific Inquiry; University Students' Understanding; Biological Experimentation; Data Interpretation; Inquiry-Based Learning

Introduction

Biology education should provide learning experiences that integrate scientific knowledge and scientific practices, enabling students not only to understand biological concepts but also to recognize how such knowledge is generated, tested, and communicated. Morrell et al., (2025) explain that scientific inquiry is a way of studying the natural world and developing explanations based on evidence. Furthermore, Čipková et al., (2026) emphasize that experimentation is an essential component of science learning because it enables direct engagement with phenomena and supports the development of conceptual understanding and scientific literacy. Within an inquiry-based learning framework, the process of generating scientific knowledge is realized through five interconnected stages: asking questions, formulating hypotheses, designing investigations, conducting investigations, and drawing conclusions (Čipková et al., 2026; Faisal & Martin, 2022; Xu et al., 2026).

The characteristics of inquiry-based approaches are highly relevant to biology education because much biological knowledge is constructed through observation and investigation of phenomena. Several studies have demonstrated that various forms of inquiry can support the development of biological and scientific competencies. Divena et al., (2021) found that Argument-Driven Inquiry influenced students' conceptual understanding and argumentation skills, whereas Husna et al., (2020) and Falentina et al., (2020) found that guided inquiry had a significant effect on critical thinking skills. These studies support inquiry-oriented instruction, but their outcome measures and school settings do not directly address associations among university students' perceptions of the three experimental domains.

Experimental activities are an essential component of inquiry-based biology learning because they provide empirical experiences through which questions and hypotheses can be tested. Jeon et al. (2021) implemented inquiry-based writing that focus differs from mapping relationships among planning, implementation, and interpretation across student-designed biology experiments. Morrell et al. (2025) found predominantly mixed understandings of inquiry among Australian third-grade students. Čipková et al. (2026) examined experimental skills in lower-secondary education, directing attention to the assessment of specific experimental practices. However, participation in inquiry activities does not necessarily ensure adequate understanding of the underlying scientific processes (Morrell et al., 2025). Previous studies have also highlighted the need for adequate support to enable students to carry out investigative processes systematically and with greater independence (Anggrella et al., 2026; Jamaluddin et al., 2024; Penn & Mavuru, 2020).

Taken together, the cited empirical studies emphasize instructional outcomes, written reasoning, school-level inquiry understanding, or teachers' perceptions. They leave a context-specific need to examine relationships among university students' perceptions of planning, implementation, and interpretation within their own biology experiments. The present study addresses this gap by providing a descriptive profile of these domains and examining their associations among first-semester Basic Biology students. Its contribution is to consider how perceptions across experimental stages vary together, while using group written work to identify complementary concerns about evidence-based interpretation. This can inform where instructors direct support within the experimental process, although the design does not evaluate the effectiveness of that support. Accordingly, the study asks: What patterns characterize students' self-reported understanding and engagement across experiment planning, implementation, and interpretation, and how are these survey domains associated?

Method

Research Design

This study employed a nonexperimental, descriptive correlational design using a post-activity survey and experimental-report assessment. The study aimed to describe students' understanding of the stages of biology experimental activities after participating in inquiry-based learning. The participants consisted of 41 first-semester students enrolled in a Basic Biology course. All participants engaged in a series of inquiry-based learning activities comprising classroom sessions and independent experimental activities conducted in the laboratory and outside the campus. The survey unit of analysis was the individual student ($n = 41$), whereas the report unit was the group ($n = 10$); the design does not support causal conclusions about learning gains or instructional effectiveness.

Inquiry-Based Learning Stages

The inquiry-based learning process was conducted through five classroom meetings, complemented by independent experimental activities. The biological concepts required to conduct the experiments had been introduced during the preceding course sessions. Thus, the experimental activities were designed to provide students with opportunities to apply their conceptual knowledge in the context of scientific investigation. The experimental activities comprised three main stages: (1) experiment planning, (2) experiment implementation, and (3) reporting and interpretation of experimental results. An overview of the inquiry-based learning stages and data collection process is presented in Figure 1.

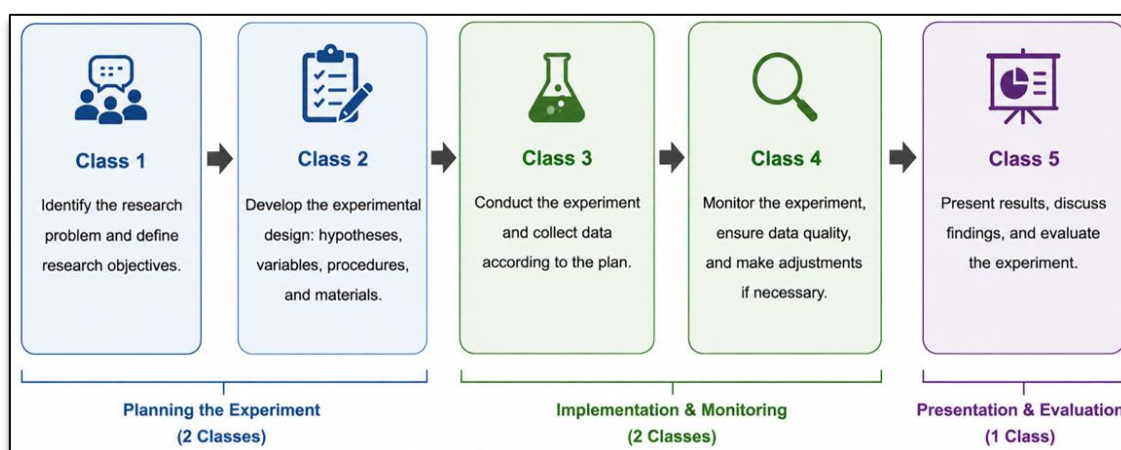


Figure 1. Steps of Inquiry-Based Learning

Instruments and Data Sources

The research data were obtained from two sources: a student survey and experimental reports. The survey instrument consisted of 10 items using a five-point Likert scale (Strongly Agree–Strongly Disagree), with four planning items, four implementation items, and two interpretation items (Table 2). Because the items also concern participation, reported actions, and opportunities, scores are interpreted as self-reported inquiry understanding and engagement rather than direct measures of experimental competence. Prior to data collection, the instrument was tested for validity using the Pearson product-moment correlation. The reported item correlation coefficients ranged from 0.611 to 0.881, exceeding the reference value of 0.308; these coefficients provide evidence of item association rather than comprehensive construct validity. The reliability test using Cronbach's alpha yielded values above 0.80 for all three categories, indicating adequate internal consistency. The second data source consisted of 10 experimental reports prepared collaboratively by students using a predetermined template. The biology experiment topics are presented in Table 1.

Table 1. List of Students' Experiment Topics

Group	Experiment Topic
1	Effect of Lamp Light and Sunlight on the Growth of Spinach (<i>Amaranthus tricolor</i>)
2	Effect of Light Intensity on Liquid Medium Contamination under Closed and Open Conditions
3	Effect of Planting Medium Type on the Growth of Mung Beans (<i>Vigna radiata</i>)
4	Osmosis in Potato (<i>Solanum tuberosum</i>)
5	Effect of Coconut Water on the Growth of Water Spinach (<i>Ipomoea reptans</i>)
6	Response of Earthworms (<i>Lumbricus terrestris</i>) to Different Touch Stimuli
7	Comparison of <i>Aspergillus</i> Growth on Bread at Different Temperatures
8	Effect of Water Salinity on the Activity of Koi Fish (<i>Cyprinus rubrofasciatus</i>)
9	Effect of Milk Type on the Quality of Yogurt Produced
10	Investigation of Germination in Mung Bean Seeds (<i>Vigna radiata</i>), Spinach Seeds (<i>Amaranthus viridis</i>), and Water Spinach Seeds (<i>Ipomoea aquatica</i>)

The survey data were analyzed using descriptive statistics, including the mean and standard deviation, across three categories: experiment planning, experiment implementation, and interpretation of experimental results. For the experimental reports, each item was scored from 0 to 2 based on the completeness of the components specified in the assessment rubric. Each report was independently assessed by two raters using the same rubric, and the final score was determined by calculating the mean score of the two raters. Subsequently, Spearman's rank-order correlation was used to examine the relationships among the stages of the experimental process based on the survey data.

Results and Discussion

Results

To describe students' understanding of the stages of biology experimentation, descriptive statistical analyses were conducted across three categories: experiment planning, experiment implementation, and interpretation of experimental results. The analysis included the mean and standard deviation for each item, as presented in Table 2.

Table 2. Descriptive Statistics of the Survey Results

Category	Item	Mean of Item	SD
Experiment Planning	1. I define the variables based on the research problem during my group's experiment planning.	4.10	0.99
	2. I actively participate in determining the experimental method that is most appropriate for our group's research objectives.	4.22	0.88
	3. My group and I anticipate potential difficulties and discuss ways to address them before starting the experiment.	3.71	1.12
	4. My group and I develop clear experimental procedures that help me understand how scientific investigations are systematically designed.	4.29	0.92
Carrying out the Experiment	5. I carefully monitor the progress of the experiment to ensure that each step is conducted according to scientific procedures.	4.22	0.88
	6. I actively participate in collecting data accurately and recognize the importance of maintaining data quality.	4.00	1.02

Category	Item	Mean of Item	SD
Interpretation of Results	7. I participate in deciding the changes needed in the experiment when the results do not match the expected outcomes.	3.90	0.86
	8. I have opportunities to directly apply scientific skills during the experiment.	3.73	0.89
	9. I use data as the basis for interpreting and drawing conclusions when analyzing experimental results.	4.12	0.81
	10. I actively connect the experimental results with relevant biological concepts when preparing the final report.	4.00	1.02

Based on the data in Table 2, for experiment planning, the highest mean was observed for the ability to develop clear experimental procedures ($M = 4.29$), whereas the lowest mean was found for the ability to anticipate potential difficulties and discuss ways to address them ($M = 3.71$). For experiment implementation, monitoring the experiment to ensure that procedures were followed appropriately yielded a relatively high mean ($M = 4.22$), while opportunities to apply scientific skills directly during the experiment had the lowest mean ($M = 3.73$). For interpretation of experimental results, using data as the basis for interpretation and drawing conclusions yielded a higher mean ($M = 4.12$) than actively connecting experimental results with relevant biological concepts ($M = 4.00$).

The category means were 4.08 for planning, 3.96 for implementation, and 4.06 for interpretation (Table 3). These values reflect positive agreement with survey statements rather than criterion-based mastery. Interpretation was not the lowest-scoring category, and the 0.12-point difference between its two items was not tested statistically. The item concerning opportunities to apply skills measures perceived opportunity rather than proficiency.

To complement the descriptive analysis in Table 2, relationships among the three survey categories were examined using Spearman's rank-order correlation, as presented in Table 3.

Table 3. Spearman Correlations Among Survey Categories

	Planning of Experiment	Implementation of Experiment	Interpretation Results
Planning of Experiment		0.849***	0.748***
Implementation of Experiment			0.861***
Interpretation Results			
Mean Category Score	4.08	3.96	4.06

Note. Values are Spearman's ρ ; category means summarize survey scores. Significance thresholds and exact p values are not reported, so interpretation is restricted to the magnitude and direction of the coefficients.

The correlations were positive and large in magnitude: planning–implementation, $\rho = 0.849$; planning–interpretation, $\rho = 0.748$; and implementation–interpretation, $\rho = 0.861$ (Table 3). Students reporting higher scores in one domain tended to report higher scores in the others. Although implementation–interpretation had the largest coefficient numerically, its difference from planning–implementation was only 0.012 and was not statistically tested. These coefficients describe associated self-reports and do not establish causal relationships or measured experimental proficiency.

The descriptive report assessment identified difficulties in describing data patterns, connecting findings with biological concepts, and supporting interpretations with evidence. Report-level scores, frequencies of these difficulties, and illustrative excerpts are not presented. These observations therefore serve as provisional contextual evidence and cannot determine the prevalence or relative severity of difficulties, or establish an individual perception–performance discrepancy.

Discussion

The findings reveal a discrepancy between students' self-reported understanding of scientific inquiry and the abilities demonstrated in their experimental reports, particularly in using data to construct scientific explanations. This condition suggests that students relatively understood the structure of inquiry activities but had not yet fully mastered the epistemic processes that connect evidence with explanations. This finding supports Morrell et al., (2025), who reported that engaging in inquiry does not necessarily result in an adequate understanding of inquiry, as well as Čipková et al., (2026), who showed that mastery of experimental skills may develop unevenly. In the context of biology education, this finding emphasizes that the success of inquiry-based learning should not be assessed solely based on the completion of procedures but also on students' ability to justify experimental decisions and appropriately use evidence.

The three correlations in Table 3 ($\rho = 0.849, 0.748, \text{ and } 0.861$) show that reported planning, implementation, and interpretation vary together. This pattern is compatible with the connected inquiry phases synthesized by Pedaste et al. (2015), but correlations between self-reports cannot demonstrate that one stage produces improvement in another. This finding is consistent with Čipková et al., (2026), who conceptualized experimental skills as a set of interconnected abilities, as well as Wahidah & Hartono, (2026) and Acarli & Dervişoğlu, (2021), who demonstrated that inquiry-based laboratory experiences can foster scientific knowledge and skills in an integrated manner. Shared item formats and general response tendencies could also contribute to the associations; these possibilities were not tested. A coherent instructional sequence linking experimental decisions, observations, and explanations is therefore an implication to examine, rather than a demonstrated effect of this study.

For interpretation, the mean for using data was 4.12 (SD = 0.81), compared with 4.00 (SD = 1.02) for linking results to biological concepts (Table 2). This small descriptive difference, together with the provisional report observations, motivates attention to evidence-to-concept reasoning but does not establish interpretation as the weakest domain. Divena et al. (2021) reported improvements in conceptual mastery and argumentation with argument-driven inquiry, while Jeon et al. (2021) foregrounded inquiry-based writing in a university laboratory setting. These studies provide a rationale for instructional support for explanations, rather than direct evidence for the causes of difficulties in the present cohort. Studies by Husna et al., (2020), Falentina et al., (2020), Siregar et al., (2022), and Kriswanti & Susantini, (2023) have also demonstrated that various forms of inquiry-based learning can support the development of critical thinking. Thus, the present findings extend these previous studies by indicating that the development of students' inquiry abilities should place particular emphasis on data interpretation and the construction of evidence-based explanations, rather than focusing primarily on conducting investigations.

Connecting evidence with a biological concept requires more than restating observations: students must identify a relevant pattern, select an explanatory mechanism, and justify why the observations support that mechanism while considering uncertainty. This need is supported by Anggrella et al., (2026) and Wiwik et al., (2025) who reported the benefits of scaffolding inquiry-based STEM for prospective biology teachers who highlighted the role of technological support in inquiry-based learning. Prompts asking students to state the data pattern, explain the evidence–mechanism link, and consider an alternative explanation are specific instructional options suggested by inquiry and writing research (Divena et al., 2021; Jeon et al., 2021). Their effectiveness should be tested rather than assumed. Thus, students' understanding of scientific inquiry becomes more meaningful when it is manifested in their ability to connect experiment planning, implementation, and interpretation as an integrated, evidence-based investigative process.

Conclusion

Students reported generally positive inquiry understanding and engagement across planning, implementation, and interpretation, and their scores in these domains were strongly associated ($\rho = 0.748\text{--}0.861$). Descriptive group-report observations identified concerns about evidence-based interpretation, suggesting that biology instruction should connect experimental planning and implementation with explicit support for explaining findings through biological concepts. The principal limitations are the single-course sample of 41 students, reliance on self-reports, and group-level report evidence without reported scores, excerpts, or inter-rater agreement. These conditions limit generalization and individual perception–performance comparisons. Future research should link individual survey responses with independently assessed explanations across courses or institutions and test explanation prompts against usual instruction using a transparent rubric and reported inter-rater agreement.

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